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POST-CRETACEOUS HISTORY OF THE MOUNTAINS OF CENTRAL WESTERN WYOMING[1]

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PART I

INTRODUCTION

Subject and scope.—In this essay it is my purpose to discuss the geologic history of a part of western Wyoming, from the close of the Cretaceous period to the present. The field under consideration is limited naturally by the district which it has been my privilege to explore. For the interpretation of Cenozoic history the district is especially favorable because that era is represented by deposits of several ages, and the physiographic conditions are so varied that they afford the means of interpreting many of the later events. It is scarcely necessary to state that many of the problems which arose in the course of the study remain unsolved or but partly solved, for such is the nature of most complex questions.

Data and acknowledgments.—The data for this work have been obtained largely from my own field examination of the district for the United States Geological Survey during the summers of 1910, 1911, 1912, and 1913. In the summer of 1910 a somewhat rapid reconnaissance trip was made from Montpelier, Idaho, through Jackson Hole and the Wind River basin to Thermopolis, Wyoming. In 1911 we ascended Green River from the Union Pacific Railroad, made a brief examination of the southern part of the Wyoming Range, carefully studied the Fall River basin and the headwaters of Green River, and devoted the remainder of the season to an examination of the Gros Ventre Range and the highlands north of it. In 1912, a detailed study was made of the west slope of the Teton Range near the Idaho line. The summer of 1913 was devoted to the Owl Creek Range and the Wind River basin and Range. In this field work I have had the assistance of Messrs. J. M. Jessup, C. W. Tomlinson, Hyrum Schneider, and D. Dale Condit.

Earlier seasons in surrounding districts afforded me an opportunity to gather information which has value by way of comparison with western Wyoming. Thus the Bighorn Mountains in north-central Wyoming were studied in 1902, the Laramie Range in the southeastern part of the state in 1907–8, and the Wasatch Range of northern Utah in 1909.

In addition, some facts and many interpretative suggestions have been obtained from the writings of other students of the

TETON BASIN
TETON RIVER
BIG HOLE MTS.
CARIBOU RANGE
SNAKE RIVER RANGE
TETON RANGE
JACKSON HOLE
JACKSON
HOBACK RANGE
GROS VENTRE RANGE
SALT RIVER RANGE
WYOMING RANGE
GREEN RANGE
SUBLETTE RANGE
IDAHO
WYOMING
SNAKE RIVER
GREEN RIVER
BUFFALO FORK
BLACK ROCK CREEK
BEAVER CREEK
GROS VENTRE RIVER
FISH CREEK
HOBACK RIVER
LABARGE CREEK
FONTENELLE CREEK
BEAR LAKE
Scale of Miles

FIG. 1

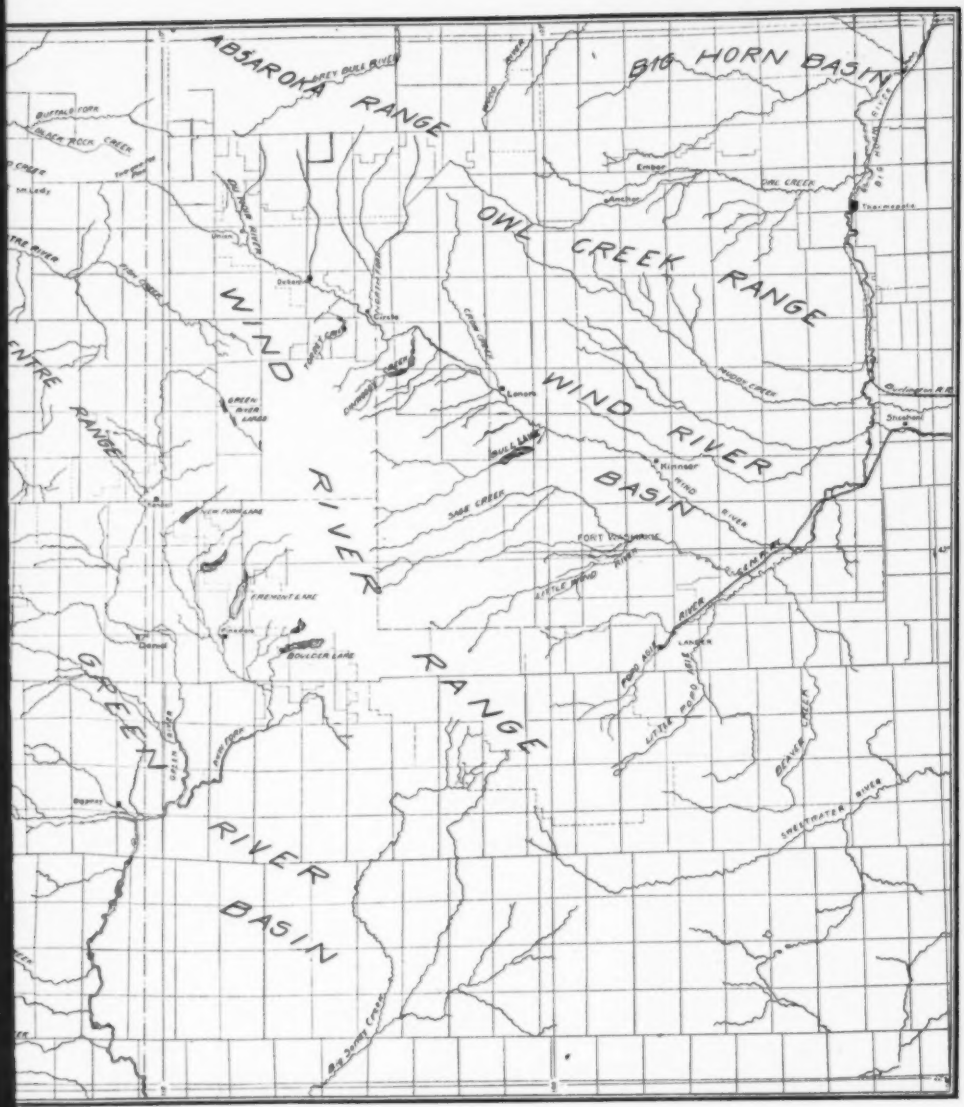
ABSAROKA RANGE
BIG HORN BASIN
OWL CREEK RANGE
WIND RIVER BASIN
WIND RIVER RANGE
GREEN RIVER BASIN
Thermopolis
Lander
Fort Washakie
Boulder Lake
Fremont Lake
New York Lake
Bull Lake
Dubois
Riverton
Kinnear
Scale of Miles

FIG. 1

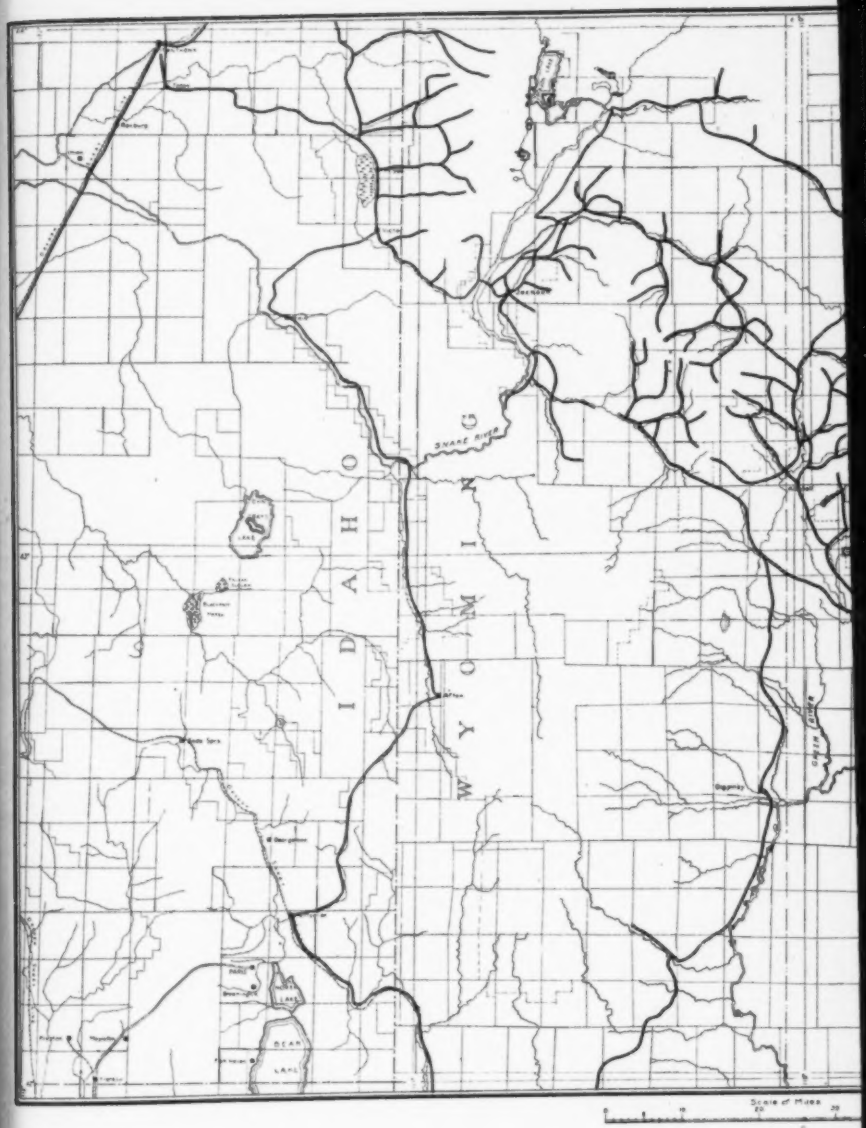

FIG. 2

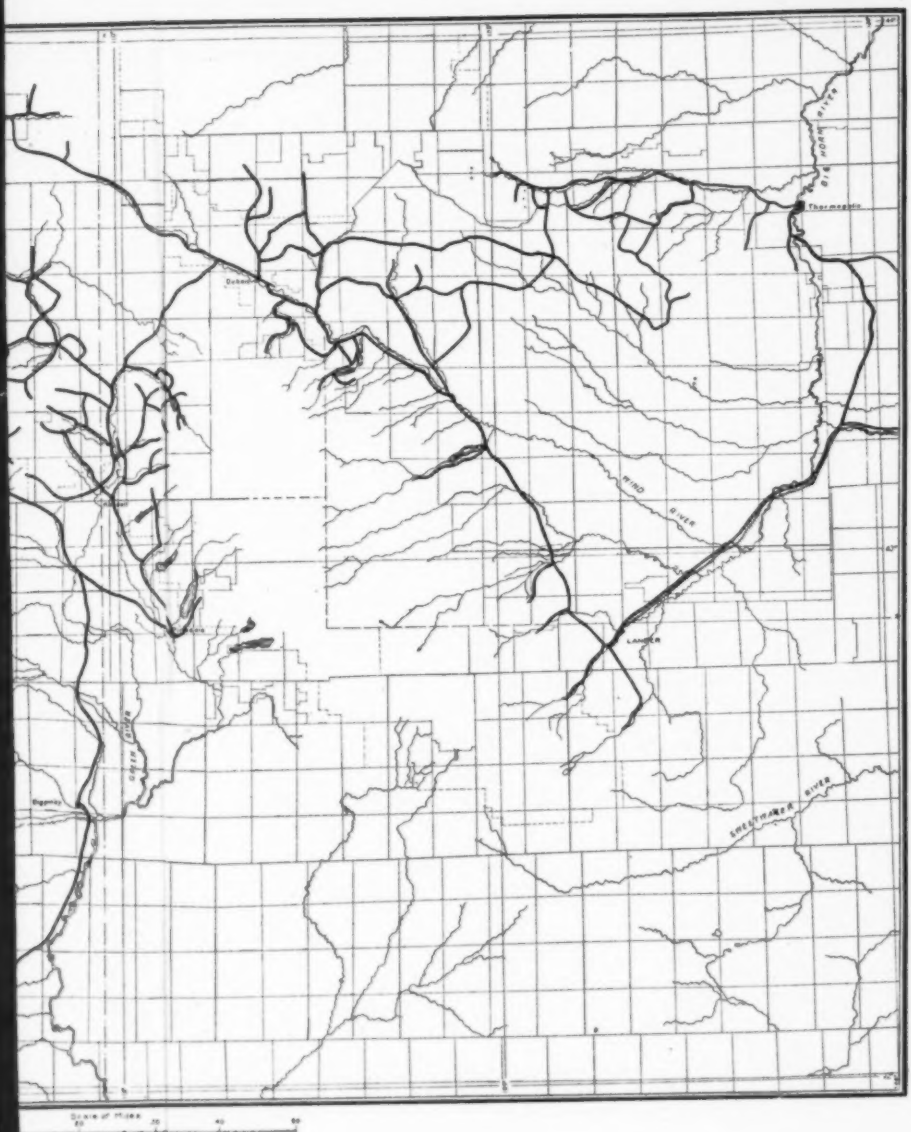
BIG HORN RIVER
Thermopolis
WIND RIVER
LANDER
GREYBULL RIVER
SHOSHONE RIVER

FIG. 2

Rocky Mountains, and especially from papers on districts outside the one immediately considered.

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A. EARLY EXPLORATIONS

1. Fremont, Lieutenant John C. On the expedition to the Rocky Mountains in 1841. A general account of the Wind River Range and the adjacent Wyoming plateaus, but there is very little strictly geologic information.

B. TERRITORIAL SURVEYS

1. U.S. Geological and Geographical Survey of the Territories ("Hayden Survey"), 1872–79. The geological exploring parties in immediate charge of Bradley, Comstock, St. John, and Endlich, and under the general supervision of F. V. Hayden, made the first thoroughgoing reconnaissance of western Wyoming and parts of adjacent states. Considering the dangerous and unsettled character of the country, the lack of previous knowledge, and the short time that could be devoted to each district, the results obtained by these parties are remarkable and deserve the highest praise. The work of Orestes St. John I have found especially trustworthy. The members of these parties made a fairly good topographic map of the district and reinforced it with perspective sketches which not only take high rank for their artistic merit, but are geologically accurate. They correctly ascertained the long sequence of rock formations and interpreted the structure of the ranges with but few mistakes. In their voluminous reports one may find many suggestions about the geologic history of the district here considered, and although some of these suggestions have not been sustained by later studies, many of them will probably stand indefinitely. Altogether, the Hayden reports contain the only comprehensive and detailed account of the geology of western Wyoming that has been written.

C. SHORTER PAPERS ON SPECIAL QUESTIONS OR ON SMALL PARTS OF THE DISTRICT

1. Eldridge, G. H. "Reconnaissance in Central Wyoming." *U.S. Geol. Survey, Bull. 119*, 1894. Brief notes on the Wind River region, with the first mention of folds affecting the Tertiary strata.
2. Weeks, F. B. "A Reconnaissance in Jackson Basin," abstract in *Science*, N.S., IX (1899), 454.
3. Woodruff, E. G. "The Lander Coal Field," *U.S. Geol. Survey, Bull. 316*, 1907, pp. 242–43. A mere note.

[1] Only such papers are here listed as have a direct bearing either upon the geology of the district in question, or upon the problems of the Cenozoic era in adjacent parts of the Rocky Mountain region.

4. Baker, C. L. A report, thus far unpublished, on the west end of the Wind River Range. In this paper there is described for the first time the Wind River peneplain. It doubtless contains many other data relating to the subject of this thesis (work done in 1908–9).
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2. Hague, Iddings, Weed, and others. "Geologic History of the Yellowstone National Park," *Smiths. Inst., Ann. Repl.*, 1891–92, pp. 133–51.
3. ———. "The Age of the Igneous Rocks of the Yellowstone National Park," *Am. Jour. Sci.*, 4th Ser., II (1896), 445–57.
4. ———. "Yellowstone Park Folio," *U.S. Geol. Survey*, No. 30, 1896.
5. ———. "Yellowstone Park," *U.S. Geol. Survey, Monograph 32*, Part 2, 1899.
6. Russell, I. C. "Geology and Water Resources of the Snake River Plain in Southern Idaho," *U.S. Geol. Survey, Bull. 199*, 1902.
7. Schultz, A.R. "Coal Fields in a Portion of Central Uinta County, Wyoming," *U.S. Geol. Survey, Bull. 316*, 1906, pp. 212–41.
8. Darton, N. H. "Geology of the Bighorn Mountains, Wyoming," *U.S. Geol. Survey, Prof. Paper 51*, 1906.
9. Fisher, C. A. "Geology of the Bighorn Basin," *U.S. Geol. Survey, Prof. Paper 53*, 1906.

10. Loomis, F. B. "Origin of the Wasatch Deposits," *Am. Jour. Sci.*, 4th Ser., XXIII (1907), 356–64.
11. Veatch, A. C., and Schultz, A. R. "Geology of Southwestern Wyoming," *U.S. Geol. Survey, Prof. Paper 56*, 1907.
12. Sinclair, W. J., and Granger, W. "Eocene and Oligocene of the Wind River and Bighorn Basins," *Bull. Am. Mus. Nat. Hist.*, XXX (1911), 83–117.
13. ———. "Notes on the Tertiary Deposits of the Bighorn Basin," *ibid.*, XXXI (1912), 57–67.
14. Sinclair, W. J. "Some Glacial Deposits East of Cody, Wyoming, and Their Relations to the Pleistocene Erosional History of the Rocky Mountain Region," *Bull. Geol. Soc. Am.*, XXIII (1912), 731 ff.
15. Umpleby, J. B. "An Old Erosion Surface in Idaho," *Jour. Geol.*, XX (1912), 139–47. Also review by E. Blackwelder, *ibid.*, XX (1912), 410–14, and reply in *ibid.*, XXI (1913), 224–31.

POST-CRETACEOUS GEOLOGIC HISTORY

Antecedent conditions.—In order to understand the effects produced by the various events and changes after the Cretaceous period, the reader should recall the general character of events before that time and particularly the conditions which had been brought about at the close of the Mesozoic era. These will be outlined without evidence or argument.

The oldest rocks of the district, generally referred to the Archean system, were folded and metamorphosed, and subsequently worn down to a peneplain before the middle of the Cambrian period. Beginning with the Cambrian and extending on through all of both Paleozoic and Mesozoic eras, sediments were spread over this peneplained surface until it had been buried to a depth of many thousand feet. Most of these sediments were deposited in the sea, but noteworthy portions were laid down upon land. Occasionally there were short episodes in which the region was subject to erosion, but these periods were not accompanied by orogenic disturbances and served to reduce the strata but little. The variety of sedimentary rocks thus produced is shown in the accompanying columnar section, and the importance of the varying erodability of the different beds will be better appreciated when the discussion of the modern physiographic forms is undertaken.

Since the latest and thickest of these deposits are partly marine and extend more or less uniformly over the entire district—except

where subsequently eroded from the crests of the anticlines—it is tolerably safe to assume that western Wyoming, near the close of the Cretaceous period, was a nearly level plain of aggradation very near sea-level, and wholly devoid of outcrops of the Paleozoic and older rocks (Fig. 3). It is deemed unnecessary to apologize here for disregarding the ancient view that each area of Archean outcrops has been an island ever since the Cambrian.

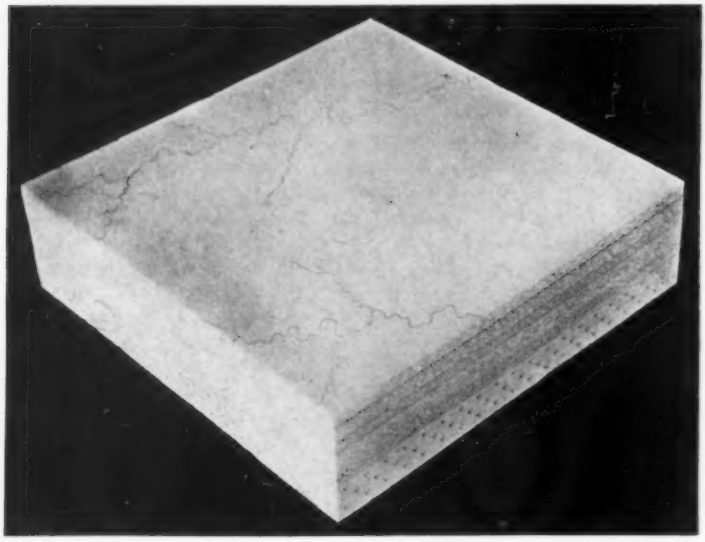

FIG. 3

Post-Cretaceous orogenic disturbance.—The Cretaceous and underlying strata have been compressed into a series of folds which generally trend northwestward through central Wyoming, and bend around to the south in the southwest part of the state. The prevailing structures in the district are open anticlines and synclines oversteepened on the southwest sides. Some of the largest folds, such as the Wind River and Gros Ventre anticlines, broke along their southwest flanks and formed overthrusts of large displacement. The most intense folding in this district generally is to be found on

the lower sides of these overthrusts. South and southwest of Jackson Hole most of the folds are much more closely appressed, and the strata generally stand upright. It is a fact worth noting that this deformation was apparently not accompanied by volcanic activity within the region under consideration. I have attempted to

TABLE I

CONDENSED TABLE OF FORMATIONS

Age	Character	Thickness in Feet	Description
Quaternary	Superficial deposits	1–500	Glacial drift, talus, landslides and earth-flows, river gravel and silt, loess, and residual soils
Tertiary (slightly disturbed)	Volcanics	Over 4,000	Stratified agglomerate and tuff with a few lava flows
	Wind River formation and associated strata	1,500 to 6,000	Largely clay and soft sandstone with local conglomerates and lava beds
Mesozoic (folded)	Shale and sandstone	6,000 to 10,000	Largely shale and clay with many beds of sandstone of which a few are thick and massive. Occasional thin layers of limestone, coal, and chert
Paleozoic (folded)	Limestone, etc.	2,000 to 3,500	Largely limestone or dolomite, some beds very massive and thick. Interbedded with shale, thin limestone, sandstone, and chert
Archean (?)	Metamorphic and igneous	Indefinite	Massive gneisses and some schists, with granitoid intrusions

show by means of a stereogram (Fig. 4) the general character of the folds and faults produced at this time as they might have appeared if they had been completed without being eroded. The effects of subsequent warping, faulting, and erosion have been eliminated. It is probable that there are more folds in the district than are shown on this model, for in other parts of the Rocky Mountains sharp folds in the Cretaceous rocks are occasionally revealed in canyons which locally cut through the superficial Tertiary cover.

The geologic age of the folding may be roughly ascertained without difficulty, but to determine it with a high degree of accuracy

and to measure its duration are not feasible on the basis of the facts obtained in this district alone. The youngest beds involved in the folding are of the Montana group, the age of which is well established by marine fossils as middle Upper Cretaceous. Still younger strata, which now stand in a nearly vertical attitude in the canyon of Buffalo Fork, have yielded plant remains, identified by Dr. F. H. Knowlton as belonging to the Fort Union flora. Elsewhere in Wyoming it is reported[1] that the Fort Union and other formations which are correlated with it have been folded to the same degree as the underlying marine Cretaceous strata and are overlain in angular unconformity by the Wasatch Eocene and equivalent

FIG. 4

formations. However, in some of these districts the Cretaceous rocks are decidedly more folded than the Fort Union beds. This has been most clearly worked out in southwestern Wyoming by Veatch and Schultz.[2] The Fort Union formation and contemporaneous deposits elsewhere are generally referred to the "basal Eocene" or Paleocene,[3] although both stratigraphically and pale-

[1] Max W. Ball and E. Stebinger, *U.S. Geol. Survey, Bull. 381*, 1910, p. 194; D. E. Winchester, *U.S. Geol. Survey, Bull. 471*, 1912, p. 47.

[2] A. C. Veatch and A. R. Schultz, "Geography and Geology of a Portion of Southwestern Wyoming," *U.S. Geol. Survey, Prof. Paper 56*, 1907.

[3] Although the term "Paleocene" has not yet been sanctioned by the U.S. Geological Survey and is not in use by all American geologists, it is so much needed in this instance in order to discriminate between "Lower Eocene" and other early Tertiary rocks still older than "Lower Eocene" that it will be freely used in this paper. The term "Eocene" will refer in these pages to those strata now commonly included in "Lower," "Middle," and "Upper Eocene," or, in terms of Rocky Mountain stratigraphy, the sequence from Wasatch to Uinta formations.

ontologically they are rather closely related to the underlying Cretaceous. Following current usage in referring these formations to the base of the Tertiary system, it appears that the principal deformation occurred after the laying-down of the Paleocene series, although in some parts of the Rocky Mountains an important orogenic movement had preceded the Paleocene.

The oldest strata which were not affected by this particular episode of deformation within the limits of the district belong to the early Tertiary series, represented east and southeast of Jackson Hole by the Pinyon conglomerate, in Green River valley by the Green River formation and associated strata, along Wind River by the Wind River formation, and in the Bighorn basin by the so-called "Wasatch" beds. Mammalian and plant fossils found at various points in these districts are said to prove that the early Tertiary strata are Eocene and that the sequence generally, although not everywhere, begins with the Lower Eocene or Wasatch stage. This is in harmony with conditions generally throughout the Rocky Mountains.

The old familiar fact is thus redetermined—that the folding took place between the close of the Cretaceous and the deposition of the Lower Eocene. Assuming that the strata in the canyon of Buffalo Fork, mentioned above, have been correctly referred to the Fort Union formation, it is suggested as probable that the most vigorous folding took place between the Paleocene and Eocene epochs.

Early Eocene erosion.—So nice is the adjustment of stream activities that no sooner did the post-Cretaceous folds commence to be bulged above the grade-level of their time than they were subject to erosion. The fact that they were thus eroded is amply attested by the unconformity at the base of the Eocene (Wasatch, etc.) strata. Since the latter now rest upon the trunkated edges of any and all of the Paleozoic and Mesozoic formations, and in some places even upon the Archean, it is evident that the post-Cretaceous folds were completely trunkated during the early part of the Eocene epoch.

Whether this resulted at any time in bringing the entire region to the condition of a peneplain is still an open question. The

surface which was finally produced just before the deposition of the Eocene strata is, however, preserved in the sub-Eocene unconformity. Profiles of its forms can be observed along the canyon walls in several of the ranges. At some points near the west end of the Owl Creek Mountains the old land surface has recently been exhumed by the denudation of the soft Eocene clays and yet not seriously disfigured during the process (Fig. 5). This surface was post-maturely hilly upon the harder rocks, and locally retained a relief of over 1,000 feet; but, as would be expected from their unresisting character, the softer Cretaceous and Jurassic beds were generally worn down to plains. In many places the

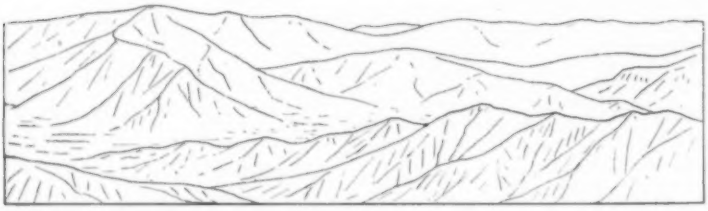

FIG. 5

Eocene now crosses the axes of the anticlines and thus shows that the ranges had been largely worn low.

Deposition of the Eocene and Oligocene formations.—Before the hilly and even mountainous parts of the early Eocene surface could be reduced to base-level, there set in more or less abruptly a change which caused the erosive processes to be supplanted in the depressions by deposition. The nature of the change is not obvious, but it may have been either a warping, which unbalanced the river systems, or a desiccation, which substituted torrential or seasonal erosion and alluviation for the slow continuous degradation of a moister epoch. Since the effects seem to have been nearly alike from Montana to Mexico, a widespread and rather uniform change is suggested. The climatic change answers this requirement, but there is uncertainty as to whether so great a thickness of sediment can be accounted for in this way. There is no question as to the competency of warping to bring about the erosion of some

areas and coincident filling of others. It appears, therefore, to be the more promising factor in this case. That the new state of things continued almost, or quite, without interruption for a long lapse of time is shown by the fact that the eroded surface is now buried in some places by a thickness of apparently conformable sediments which cannot well be less than 4,000 feet thick and may easily be much more. Remnants of these beds are now to be found in all the principal lowlands of the district, such as Green River basin, Jackson Hole, and Wind River valley, and also in the Mount Leidy highlands at the northwest end of the Wind River uplift. The strata vary considerably from place to place, as they might be expected to in view of their terrestrial origin and the irregular surface upon which they were deposited.

The origin of these Tertiary deposits is not wholly obvious, and their designation as "lake-beds" by the Hayden Survey is open to grave doubt. It is safe to say that they are not marine, for instead of marine fossils they contain the remains of land plants and land mammals, as well as of freshwater fishes and mollusks. As working hypotheses we may suppose that they could have been deposited (*a*) by lakes and marshes, (*b*) by graded streams upon their floodplains, (*c*) by wet-weather streams making alluvial fans, or (*d*) by the wind upon dry land surfaces. It is not inherently improbable that each of these agencies may have played an important part. The problem compels more analysis.

The Pinyon conglomerate (Fig. 6) of the Mount Leidy highlands has already been mentioned as highly suggestive of the work of powerful aggrading streams with constantly shifting channels. It appears to be identical with deposits being made today by those means, and no other agency seems competent to produce it. The pebbles are nearly all quartzose in composition and are in large part foreign to the district. This suggests that they have been transported far, and that they are the residue of long-continued attrition. If this be granted, it may be taken to indicate that the Pinyon conglomerate was deposited largely by aggrading rivers of considerable length and power, rather than chiefly by local creeks from the surrounding mountains.

Along the flanks of the Owl Creek and Wind River mountain ranges the basal part of the Tertiary strata contains wedge-shaped beds of coarse conglomerate interleaved with the finer sediments and pinching out away from the mountains. The pebbles are ill rounded and consist wholly of rocks which outcrop near by. The lithologic varieties are many and not well assorted. These facts suggest the local deposition of alluvial fans by mountain creeks along the border of a lowland. Similar conditions exist today in the California valley.

FIG. 6

Again, some small parts of the sequence have evidently been deposited in lakes, since from the valley of the north fork of the Gros Ventre River, Mr. Perry[1] of the Hayden Survey reports five successive beds of freshwater limestone containing recognizable lacustrine shells. There is equally good evidence that some of the material was laid down in marshes, for thin lignitic seams have been found in many localities, and especially in the section last mentioned. There Perry found in a single exposure no less than forty-seven beds of lignite, most of them very thin. Similar beds occur in the Bighorn and Wind River basins.

[1] Hayden Survey report for 1878, Part 2, pp. 223–24.

The banded clays, usually of pink and gray colors, which constitute the bulk of the Tertiary beds along the head of the Gros Ventre River, throughout the Wind River basin, and in the Bighorn basin, suggest a different mode of origin. Sinclair,[1] from a careful study of these clays and their associated sandy beds in the Bighorn basin, reaches the conclusion that they are river floodplain deposits laid down under a moderately dry climate. The color banding he ascribes to alternating cycles of moist and dry climate (pp. 116–17). So regular is the repetition of their red and gray layers that an oscillating control is strongly indicated. Loomis[2] also reached the conclusion that the clays and silts of the Wasatch formation in the Bighorn basin were floodplain deposits. In this connection he called attention to the fact that, of the very large number of fossils which had been found in the beds, only 10 per cent are aquatic, whereas the most abundant forms are horses and other animals which frequent the relatively dry plains. Even the aquatic animals were turtles, crocodiles, and fishes, all of which inhabit rivers.

Such observations as I have made tend to confirm this hypothesis of floodplain deposition, under subarid or steppe conditions. The more sandy layers consist of small angular fragments of quartz, prisms and slivers of hornblende, hexagonal plates of mica, and sharp bits of feldspar. No volcanic ash was observed in the typical striped Wind River beds. The undecayed condition of the grains precludes a warm moist climate, and the prevalent reddish or pinkish color is evidence of thorough oxidation, which would have been inhibited in a cold moist climate. The general lack of abrasion suggests that the particles have not been transported very far, or at least were not worked over continuously for a long space of time. To Loomis and Sinclair's hypothesis I may add the suggestion that the Eocene sediments probably originated as regolith due to rock disintegration and eolian abrasion in a dry climate. Much of the angular quartz and feldspar dust may well be the product of sandblast action upon rock outcrops. The regolith, once formed, was

[1] W. J. Sinclair and W. Granger, "Eocene and Oligocene of the Wind River and Bighorn Basins," *Am. Mus. Nat. Hist. Bull.*, XXX (1911), 83–117.

[2] F. B. Loomis, "Origin of the Wasatch Deposits," *Am. Jour. Sci.*, XXIII (1907), 362.

probably washed down from its points of origin by temporary hill streams, sifted from the coarser fragments, imperfectly sorted mineralogically, and soon deposited on the flat bottoms of broad, intermontane basins. It is a suggestive fact that the sandy silt taken from a cut bank in the broad floodplain of Owl Creek has the same structural, textural, and mineral characteristics as some of the Wind River strata. This silt is a modern floodplain deposit in a drainage basin which does not contain outcrops of the typical Wind River strata. A mere reworking of the Eocene material in this instance is scarcely possible.

Some parts of the Tertiary sequence are obviously volcanic in origin. Thus, along the east side of Jackson Hole, there are considerable flows of andesite and rhyolite in the lower part of the formation. If we may rely upon lithologic similarity and field relations, we may correlate with these the flows which cloak the west slope of the Teton Range, although the relationship is not yet firmly established. At the northwest end of the Wind River Range, where it articulates with the mountains of Yellowstone Park, thick beds of volcanic ash and agglomerate with interbedded glassy lava flows rest upon the pre-Tertiary folded rocks, but are themselves younger than the Wind River Eocene. Traced eastward to Horse Creek, the Washakee Needles, and the valley of Owl Creek, this thick volcanic series is found to rest conformably upon the striped clays of the Wind River formation, with which they intergrade through gray, plant-bearing shales and greenish volcanic sandstones containing petrified logs. A closer examination of the volcanic beds shows that some of them are massive agglomerates, devoid of stratification, whereas other beds are distinctly stratified, cross-bedded, and occasionally interrupted by lenticular sheets of coarse gravel, suggestive of stream channels. The conditions indicated are those which would be found upon low gradient river plains adjacent to active volcanoes.

In order to place these conditions as closely as possible in chronology, it would be necessary to know the ages of all parts of this Tertiary sequence. Unfortunately, this is not fully understood. On the basis of freshwater shells, and land plant leaves which were found in the valley of the Gros Ventre River by the

members of the Hayden Survey, the strata were tentatively correlated with the Wasatch of Utah. Fossil mammals from the Wind River basin[1] have recently been correlated with those of the Wind River and Uinta formations of the Eocene and with those of Lower Oligocene. In the southwest part of the Bighorn basin abundant mammals belonging to the typical Wasatch have been found by Wortmann, Loomis, Granger, and others. The beds in which they occur are so closely similar to those in the Upper Wind River valley and near the head of the Gros Ventre River that the intercorrelation of all three is strongly suggested. Since the volcanic Tertiary beds lie almost entirely at higher elevations, and, where both formations are present, at stratigraphically higher horizons than the Wind River formation, they are probably not older than Upper Eocene. Sinclair and Granger have found Lower Oligocene fossils in beds of tuff and agglomerate east of Lander. Older Tertiary beds in that vicinity do not contain volcanic materials, except for two or three beds of ash in the Middle or Upper Eocene.

In review, the evidence relating to the Tertiary sediments seems to indicate that, from the Wasatch or Lower Eocene epoch until at least the early Oligocene, west-central Wyoming was subject to a semi-arid climate in which there were, however, considerable fluctuations; that streams made widespread deposits in the lowlands; that these were largely of clay, silt, and sand but locally of gravel; and that the wind was a modifying rather than a controlling agency in the process; that lakes and marshes existed locally from time to time; and that volcanic eruptions in the western part of the district, and late in the sedimentary interval, scattered ash and cinders over much of the district. No matter what hypothesis of the origin of the Tertiary beds is adopted, it leads to the conclusion that by the Oligocene epoch the processes of sedimentation had produced one or more broad flat or gently graded plains beneath which were buried deeply the old Eocene hills and many of the lower mountains. There seems to be no means of knowing whether all the ranges were buried by the Tertiary deposits. They now cover

[1] W. J. Sinclair and W. Granger, "Eocene and Oligocene of the Wind River and Bighorn Basins," *Bull. Am. Mus. Nat. Hist.*, XXX (1911), 83–117.

both ends of the Wind River and Owl Creek anticlines and have evidently been eroded from large areas which they once covered. On the other hand, there seems to be no good reason to suppose that some of the principal mountain ranges did not rise above the aggraded plains somewhat as they now do in the Bonneville Lake basin of Utah (Fig. 7).

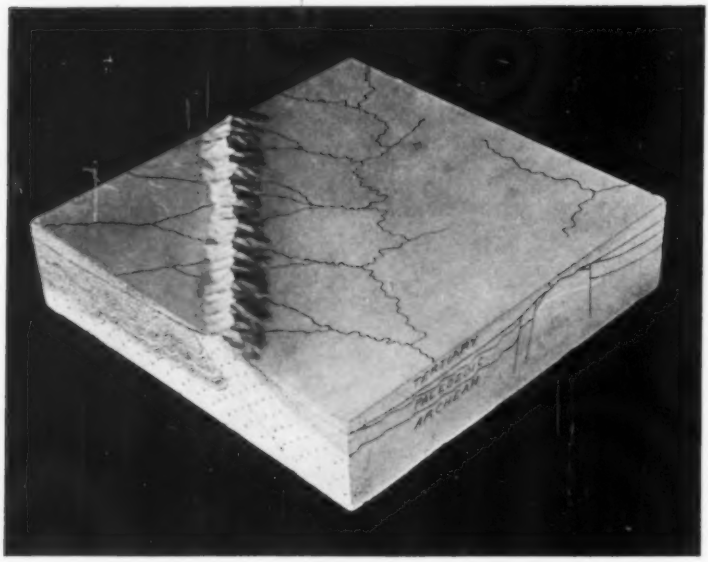

FIG. 7

Mid-Tertiary deformation.—The early Tertiary sediments no longer lie in their original almost horizontal attitude. Nearly everywhere they have been tilted gently, and in a few places bent into folds and broken by faults of large displacement. In Jackson Hole the beds of travertine or freshwater limestone with lava flows dip 10–15° toward the west. Near the forks of the Gros Ventre River the alternating sandstones and clays dip 12–14° northeastward. Near Dubois in the Wind River basin, the finely laminated Eocene clays dip 5–8° away from the Wind River Range. In the southwest part of the Bighorn basin, Sinclair and Granger observed

an anticline in the Wasatch deposits, the dips being 5–7° on either limb. In the slope just east of the E. A. ranch, north of Dubois, there is a fold the southern limb of which dips at an angle of about 35°. The strongest folding I have yet seen in the Wind River beds was found on the north fork of Wind River in the southwest corner of the Kirwin quadrangle (see Fig. 8). There a relatively sharp anticline between two broad flattish synclines exhibits dips of from 5° to over 50°. Although in a few cases the dips may be initial, it is improbable that the fine clays were deposited at angles of even 5–10°.

Faulting is more common than folding in the Eocene strata. Near the mouth of Dinwoody Creek on the north side of the upper

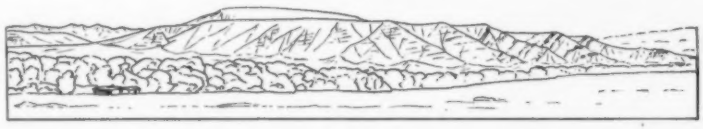

FIG. 8

course of Wind River, a fault of several hundred feet displacement interrupts the nearly horizontal Wind River beds (Fig. 9). On the northwest side of the Teton Range a normal fault of at least 1,500 feet displacement drops the Tertiary volcanic breccias and rhyolitic flows down against Paleozoic strata. At Granite Falls, and again along Jack Creek, both on the south side of the Gros Ventre Range, a coarse conglomerate, apparently the same as the Pinyon formation farther north, has been faulted down against the Paleozoic rocks (Fig. 10). In the southern part of Jackson Hole the freshwater Eocene limestone, with its interbedded lava flows, is several times repeated in successive buttes rising above the alluvial floor of the valley. The structure is readily explained by assuming several normal faults with a downthrow on the east, but if the faults exist they are concealed by the alluvial deposits. On the west front of the Hoback Range the Tertiary beds have been faulted down against the Carboniferous. There is abundant circumstantial evidence to indicate that a great fault marks the east base of the Teton Range, cutting off the Paleozoic and Mesozoic

succession to the east, and raising on the west a lofty wall of Archean gneiss. The exposed scarp along this fault is now more than 7,000 feet high (see Figs. 16 and 27) and the total stratigraphic throw can hardly be less than twice that amount.[1]

This deformation evidently took place later than the deposition of the conformable Eocene and Oligocene strata. If disturbances

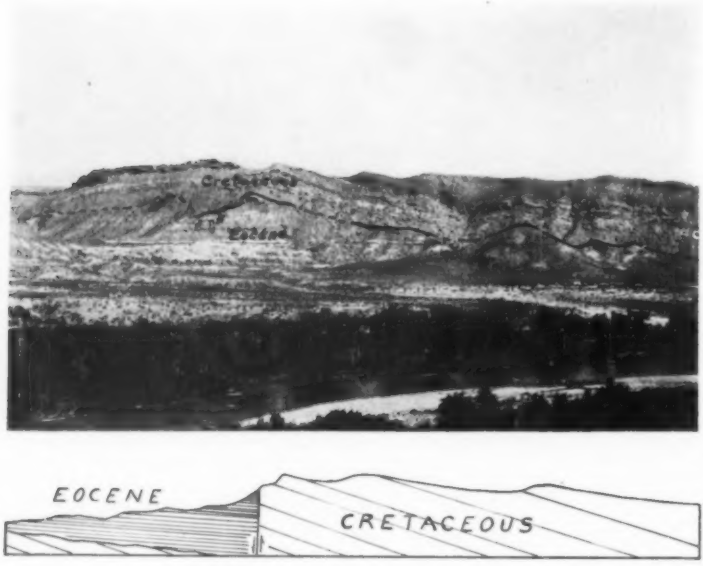

FIG. 9

of this kind had occurred within that depositional interval, they would have caused important unconformities and changes in sedimentation, which are not in evidence. They must also have taken place long before the deposition of the older glacial drift, for the moraines have not been disturbed and on the contrary lie across fault traces along which the scarps have long since disappeared. As will be shown later, allowance must also be made

[1] For a discussion of the question whether this is a recent fault scarp or an old "fault-line scarp" (W. M. Davis, *Bull. Geol. Soc. Am.*, XXIV [1913], 187–216) see below.

here for the making of the high peneplain and the subsequent sculpturing of the modern topography before the last stage of glaciation. Since we cannot yet translate physiographic results into years or even into geologic periods, the portion of the Tertiary and Quaternary periods to be allowed for these events cannot be estimated with any degree of confidence. From the evidence within the district, then, it is justifiable to conclude only that the deformation probably followed the early Oligocene and preceded the Pleistocene.

From a general study of the tectonic disturbances at various times in the earth's history, such as the Appalachian revolution, the

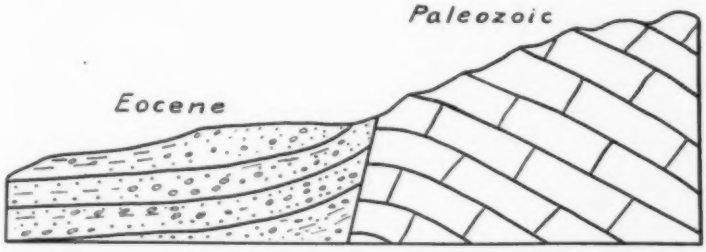

FIG. 10

late Jurassic orogeny of the Pacific, and many others, it seems to be established as a general rule that deformative movements are roughly periodic and that they affect long belts which are continental or even world-wide in their dimensions. It seems fairly safe to assume that the deformative movements evidenced in western Wyoming accorded with this principle, and were manifestations of a much more widespread disturbance, the effects of which should be recognized in adjacent states. It is also self-evident that any such widespread disturbance would cause notable changes in the relief of the land, and would revolutionize the physiographic activities of the region so affected. These changes should now be found in the unconformities or in sudden changes in the character of sediments.

In the Coast Ranges of California, Arnold and others appear to have shown beyond reasonable doubt that sedimentation prevailed

rather generally and without notable interruption from the early Eocene to about the middle of the Miocene as those epochs are now generally correlated, but that near the middle of the Miocene the Tertiary beds were folded strongly so that the late Miocene sediments now rest with marked discordance upon the early Miocene and older strata. In central Washington, Willis, Smith, and

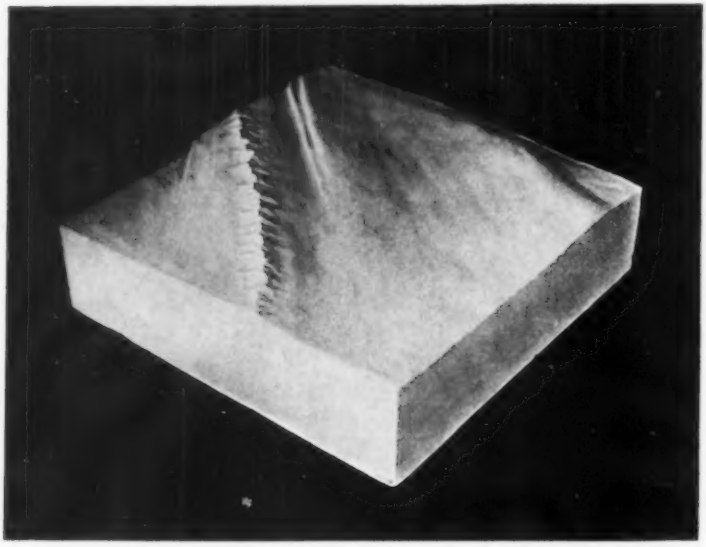

FIG. 11

Calkins have likewise shown that rocks containing early Miocene plants are highly folded and intruded by granites, and that upon their trunkated edges late Miocene lavas and sedimentary beds lie with but little change in their original attitude. In the Grand Canyon region of Arizona the studies of Huntington, Goldthwait, and others lead them to the conclusion that the conspicuous faults of the plateau region were begun long before the late volcanic eruptions, but also long after the gentle folding of the Cretaceous beds. There have also been subsequent movements along the same fractures. A broad study of the Middle Tertiary disturbance has

recently been made by Mr. Hyrum Schneider, and recorded in his manuscript thesis for the M.A. degree at the University of Wisconsin in 1911 (not published). He concludes that the Middle Miocene disturbance affected all of the Cordilleran region, being expressed as folding along the Pacific coast and in Washington, but chiefly by warping and faulting in the Rocky Mountain province.

To summarize these considerations, it may be said then that the sedimentary formations deposited in the early part of the Tertiary period were afterward very gently folded and broken along a few scattered normal faults (see Fig. 11), and that the event took place in the midst of Tertiary time and probably in the middle of the Miocene epoch. Inasmuch as the Tertiary beds almost everywhere dip away from the anticlinal ranges and toward the synclinal basins, it seems evident that the mid-Tertiary deformation merely emphasized the structures produced at the close of the Cretaceous. The faults do not, however, in all cases follow these older structures, for in the Teton Range the original Gros Ventre anticline, which had a northwest-southeast trend, is diagonally transected by several large north-south faults.

[*To be continued*]

THE CANTWELL FORMATION: A CONTINENTAL DEPOSIT OF TERTIARY AGE IN THE ALASKA RANGE[1]

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Introductory statement.—The Cantwell formation comprises a series of conglomerates and finer clastic sediments of important though restricted development within the Alaska Range. These rocks form a belt from 3 to 23 miles in width, which has its beginning near the northeast base of Mount McKinley and extends thence eastward for at least 100 miles to Cathedral Mountain at the head of Susitna River. Its members attain their most typical and maximum expression adjacent to the Nenana Valley, intermediate between those two points.

Historical.—In 1898, during a hasty exploratory trip into the Alaska Range, Elridge noted a "series of conglomerates and coarse sandstones" on the Nenana (then called Cantwell) River, between two tributaries later designated as Jack River and Yanert Fork, and referred briefly to this group of rocks as the Cantwell Conglomerate.[2] Brooks and Prindle in 1902, on a geological reconnaissance of the Mount McKinley region, came across similar rocks at the foot of Muldrow Glacier[3] near Mount McKinley, and following along their northern border traced their extension eastward into the Yanert Fork basin, mapping the area as the

[1] Published with the permission of the Director of the United States Geological Survey. The field work upon which this paper is based was done by F. H. Moffit and the writer, and the latter is indebted to Mr. Moffit for helpful suggestions in its preparation.

[2] George H. Elridge, "A Reconnaissance in the Sushitna Basin and Adjacent Territory, Alaska, in 1898"; *United States Geol. Survey Twentieth Ann. Rept.* (1898–99), Pt. 7, p. 16; also map 3.

[3] They also found a small area 75 miles southwest of that point near Mount Russell of the Alaska Range.

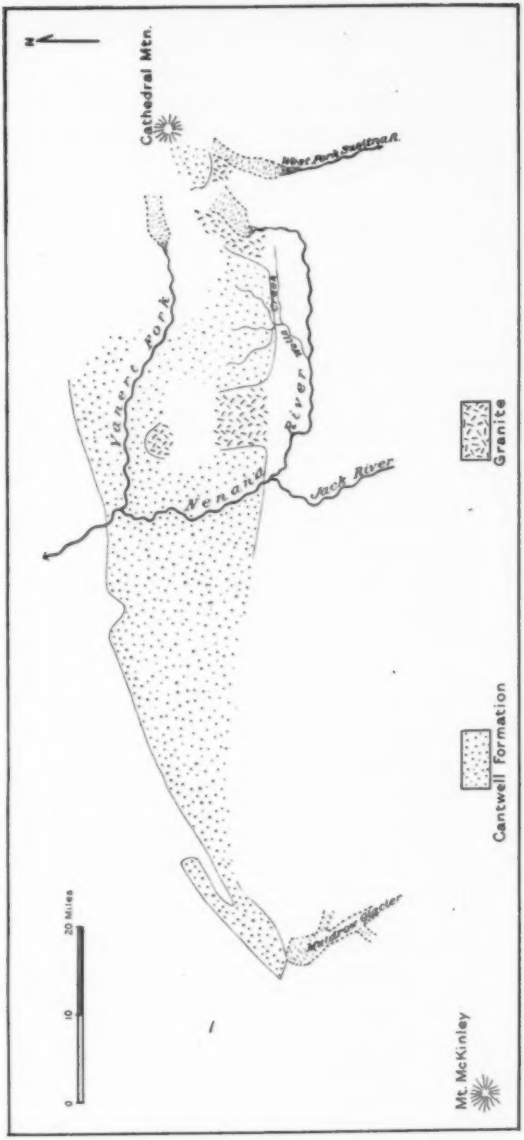


FIG. 1.—Sketch map showing the distribution of the Cantwell formation

Cantwell formation.[1] In 1913 Moffit and Pogue, during a reconnaissance survey of the Broad Pass region, encountered this belt at the mouth of Jack River and studied in some detail its eastward development up to the West Fork Glacier of Susitna River. The present paper deals primarily with this eastward extension of the Cantwell, although it is believed that the conclusions are applicable to the formation in its entirety.

Character.—In its westward extent and along its northern border, the Cantwell formation is characterized by Brooks[2] as follows:

> The Cantwell formation includes a series of heavy conglomerates interbedded with a few shale layers and succeeded by finer conglomerates and red sandstones interbedded with gray and black clay shales. . . . . The basal conglomerate of this formation is made up chiefly of well-rounded white quartz and chert pebbles, the largest of which are 2 inches in diameter. The basal character of the conglomerate is well illustrated in several localities where it rests uncomformably on the older rocks and also contains rounded fragments of them. That part of the formation seen by Elridge contained only the basal beds of the series. On being traced to the north and west these are found to be succeeded by reddish sandstone and gray, drab, and black shales. The sandstones are in some places bright red, but grade from this into a reddish-brown to medium-brown color. The shales are both argillaceous and arenaceous, the latter phase grading into a shaly sandstone. Some of them carry a large amount of carbonaceous matter, and coal seams are interbedded with these rocks, but those seen by the writer appear not to have any commercial importance. . . . .

In the area traversed by the present writer, the Cantwell formation attains its most representative development along the northward course of Nenana River below the mouth of Jack River. The stream here cuts through mountains of conglomerate, which shows in heavy massive beds up to 100 feet and more in thickness, of gentle dip and somber aspect, alternating with subordinate beds of sandstone and argillite. Eastward from the mouth of Jack River the formation changes progressively in character: The conglomerate members become less conspicuous, with increasing prominence of graywacke, sandstone, and carbonaceous shale; while the

[1] Alfred H. Brooks, "The Mount McKinley Region, Alaska," *United States Geol. Survey, Prof. Paper 70* (1911), Plate 9.

[2] *Op. cit.*, p. 78.

rocks no longer remain massive, but show greater and greater schistosity, the finer members passing finally into slates and phyllites, the coarser ones into mica schists.

The massive conglomerate was examined with especial care just east of the mouth of Jack River, where it forms prominent cliffs along the southern face of the Alaska Range. The rock is composed of grains, pebbles, and cobbles (observed up to 7 inches in length) of quartz, quartzite, slate, rhyolite porphyry (?), and perhaps other rocks, set in siliceous cement. Intercalated between these massive beds are thinner members of sandstone, quartzite, and dark-blue carbonaceous argillite. The formation is separated here from the Paleozoic limestone along its southern border by a narrow intrusion of granite, connecting eastward with a large area that intercepts the sediments for a course of several miles.

East of the granite intrusion the Cantwell formation reappears in a more accessible portion of the Alaska Range embracing the headwater region of Wells Creek. This area extends eastward for 13 miles almost to the Nenana Glacier, where it is interrupted by another great granite intrusion. The sediments show the effects of more compression than do the massive beds to the west, and in consequence display considerable schistosity. This Wells Creek area was carefully studied in its western, central, and eastern portions.

In its western portion, a good section was obtained up a small draw from the valley gravels to the mountain top. The lowermost 1,500 feet consists predominantly of massive to somewhat schistose graywackes of dark-gray color, composed of subangular to rounded pieces of quartz and black slate set in siliceous cement. This rock carries intercalated beds of black carbonaceous shales with abundant impressions of leaves and of siliceous conglomerate, in part somewhat schistose. The remaining 600 feet to the mountain top is composed of prominent, heavy beds of a severely mashed phase of the conglomerate, light greenish to yellowish in color, in places so schistose that the original texture is nearly obliterated. The average rock, however, shows the coarser components as elongated lenses, resembling so-called "stretched-pebbles," enwrapped by the finer constituents, which have been rendered in part

micaceous. The beds dip northward at angles of 35° to 60°, indicating that the folding is less gentle than to the west.

In its central portion the Wells Creek development of the Cantwell was again examined in detail. The adjoined section of the lowermost portion in contact with underlying granite indicates the rapid variation in conditions that gave rise to this series.

SECTION OF LOWERMOST PORTION OF CANTWELL FORMATION NEAR WELLS CREEK

Schistose conglomerate	15 feet
Silicified tuff[1]	15 "
Alternations of schistose conglomerate and schistose graywacke, carrying beds of shattered black slate and lens-like intercalations of tuff	50 "
Dense, light-colored tuff, very hard	5 "
Fairly schistose conglomerate, grading into schistose graywacke, which in turn grades into schistose conglomerate; the whole carrying pinching and swelling lenticular beds of tuff	15 "
Graywacke, with lenses of quartzite and of shattered carbonaceous slate	30 "
Fairly massive siliceous conglomerate	2 "
Graywacke	3 "
Carbonaceous slate, badly shattered and slickensided	8 "
Graywacke, slightly schistose	15 "
Crushed slate and schistose graywacke	5 "
Graywacke, fairly massive	5 "
Covered, mostly altered graywacke	20 "
Schistose and altered graywacke, injected with quartz stringers and lenses	10 "
Granite, exposed	30 "
Glacial gravels to valley bottom.	
	228 feet

For a few hundred feet above this section the rocks are not exposed; then there appears a narrow bed of shale, bordered by a large barren quartz vein, which shows beneath a heavy somewhat contorted bed of comparatively massive conglomerate composed predominantly of white quartz pebbles averaging three-

[1] As shown by the microscope, this rock is composed of small pieces of quartz, with some orthoclase and a very little plagioclase—all distinctly fragmental—set in a dense, microcrystalline ground.

fourths of an inch in diameter. From this exposure to the mountain top, a vertical distance of about 1,100 feet, the rocks are dominantly black shale with plant impressions, alternating with beds of massive graywacke, in some places approximating a sandstone. Near the eastern base of this mountain the carbonaceous, plant-bearing shales were observed to carry 2- to 2½-inch seams of impure lignitic coal. For 2½ miles north of this point mashed conglomerate alternates with dark-blue to black slate (resulting from the metamorphism of the carbonaceous shales), some phases showing a crinkly surface of satin-like luster. Many of the rocks here might properly be termed schists, and the formation as a whole presents a black aspect due to the widespread dissemination of carbonaceous material.

A traverse was carried up a stream farther eastward in the Wells Creek area. Near the southern border of the formation, this stream exposes closely folded beds of slate, graywacke, and conglomerate, all severely mashed, the conglomerate almost beyond recognition. The slate is also badly crushed and slickensides are prominently developed. For two miles above these outcrops the formation seems about equally divided between slate, graywacke, and conglomerate, the last two having suffered most from the regional metamorphism, although much of the slate has a crinkled surface, suggesting the intensity of the compression to which the rocks were subjected. Throughout this extent the rocks are steeply dipping and apparently vary from 80° N. to 80° S. In places are crinklings and plications suggestive of sharp folding, and many specimens of a peculiar, plicated phase of mashed conglomerate were observed in talus fans. The formation as a whole is dominantly dark-grayish to black in color.

East of the Wells Creek basin, the Cantwell is replaced by a large intrusion of granitic character, forming a rugged mountain range surrounding the Nenana Glacier. A few miles northeast of the glacier, at the foot of Cathedral Mountain, the Cantwell apparently appears again; this area was not directly accessible, though observable with field glass and through the agency of glacially transported specimens. The sediments here consist of dark-colored slates and mica schists, the latter representing the coarser clastics

severely mashed. A typical example of the mica schist is dark-reddish to bluish-gray in color, weathering to an iron-stained surface glistening with mica scales along its planes of foliation and presenting on transverse break thin quartzose lenses, deformed survivors of original pebbles. It is only after having traced the Cantwell through its progressive stages of metamorphism from west to east that an observer would recognize this type as the mashed equivalent of the massive conglomerate so extensively developed near the mouth of Jack River, 35 miles to the west.

Associated igneous rocks.—In the western extension of the formation lava flows of andesitic, rhyolitic, and basaltic character are interbedded with the conglomerate, and these intercalations are especially prevalent toward the Nenana Valley, in some localities equaling the sediments in thickness.[1] West of the Nenana the Cantwell is cut by dikes of diabase and stocks of granite. Reference has already been made to the granite batholiths that invade the Cantwell sediments east of the Nenana Canyon. Adjacent to these areas the sediments are traversed by abundant dikes of rhyolite porphyry and diorite porphyry, the former especially conspicuous near the head of Wells Creek.

Structure.—The structure of the Cantwell formation has been suggested in the preceding paragraphs. Its low northward dip and unmetamorphosed character on the west, with increasingly steeper dips and development of schistose textures along its eastward course, point to folding, gentle to the west, more and more intense to the east. The trend of the formation, and of the axis of folding, as indicated by numerous strike measurements, as well as by the course of the southern boundary of the formation, is about N. 80° E.

The inclination of the massive conglomerate beds where the Nenana River turns northward and cuts through them indicates that the southern face of the mountains here represents the beveled upturned edge of a gentle synclinal fold. According to Brooks[2] this type of broad open folding holds for the westward extension of the formation. At the head of Wells Creek the Cantwell is structurally more complicated than in the area just noted. It

[1] Brooks, *op. cit.*, p. 79.

[2] *Op. cit.*, p. 79; also section CD on geologic map, Plate 9.

here shows steep, though variable, dips, both to the north and to the south; and transverse to the trend of the sequence displays considerable variation in the degree of dynamic metamorphism, the rocks ranging from fairly massive to schistose. These observations indicate that the rocks have been subjected to considerable compression, and it is believed that the gentle folds on the west pass eastward into more intense and complicated folds, not isoclinal, but with axial planes variously inclined on an east-west axis.

Although no faults were directly observed in the portions of the Cantwell examined, faulting was undoubtedly a resultant of the compressive forces to which the terrane has been subjected. It would appear from the increasing pressure effects to the east that the formation as a whole had suffered a differential degree of compression. Yet the possibility must not be overlooked that in the massive areas extensive faulting may have relieved the stresses that in the absence of these places of yielding would have produced close folding and schistosity there also. In the westward part of the formation (west of the Nenana), where the rocks are massive and folding gently, Brooks[1] observed a number of faults consequent upon the folding.[2]

Contact relations.—Along the northern border, according to Brooks, the Cantwell rests unconformably upon Paleozoic rocks. Along the eastern portion of the southern border, the relation to the bordering Paleozoic sediments is obscured by granite intrusions and glacial gravels, but the contact is believed to be characterized by an unconformity, although there is some evidence that the plane of separation is one of fault movement. The coming to place of the extensive granite batholiths seems to have had little structural or mineralogic effect upon the invaded sediments.

Thickness.—The thickness of the Cantwell formation was obtained with greatest accuracy in the section east of the mouth of

[1] *Op. cit.*, pp. 79–80.

[2] Brooks (*op. cit.*, p. 79) suggests that the Cantwell is not so sharply folded as the adjacent formation, "because the massive beds were able to resist the movement, some of which has been taken up by lines of shearing that have followed the shale beds and the lines of parting between the shales and the massive beds."

Jack River, where calculations based upon aneroid and triangulation measurements show a vertical development of about 2,700 feet. In the headwater region of the Toklat basin about 25 miles to the west, Brooks[1] found that the thickness there exposed is at least 2,000 feet. These figures do not represent the total thickness of sediments as deposited, because the top of the formation is a surface of erosion, from which an uppermost portion of unknown thickness has been removed.

Age and correlation.—The Cantwell formation is assigned to the Tertiary on the basis of plant remains found in some abundance in the Wells Creek area. The following forms were identified by Drs. F. H. Knowlton and Arthur Hollick, who report that the material is of Tertiary age:

Taxodium tinajorum Heer.
Taxodium dubium (Sternberg) Heer?
Sequoia langsdorfii (Brongniart) Heer?
Populus arctica Heer?
Daphnogene Kanii Heer.
Aspidium Heerii Ettingshausen?
Ginkgo adiantoides (Unger) Heer?

In the report on the Mount McKinley region[2] the Cantwell was provisionally referred to the Carboniferous, although its lithologic resemblance to several occurrences of the Kenai formation (Eocene) was noted and the possibilities of younger age fully recognized. The extent and relation of the plant-bearing area surrounding upper Wells Creek and the fact that a locality within the western portion of the Cantwell has also furnished Tertiary plant remains showing identical species[3] would seem to fairly establish the present age assignment.[4]

[1] *Op. cit.*, p. 81. [2] *United States Geol. Survey, Prof. Paper 70*, 1912.

[3] Brooks, *op. cit.*, p. 82. This occurrence was interpreted as an infaulted block and the fossil evidence was not regarded as applicable to the surrounding formation.

[4] The possibility must be recognized that future detailed work may result in a subdivision of the Cantwell, as in its western portion in particular the members in which conglomerate beds dominate are succeeded by a series of shales and sandstones. It seems likely, however, that these upper members are merely an expression of normal, changing topographic conditions in the region of supply, rather than the result of a distinctly later epoch of sedimentation. In its eastern portion, where observed by the present writer, the formation appears definitely a unit.

The Cantwell as indicated by its plant remains and character is of Eocene age and corresponds in whole or in part to the Kenai formation, widely distributed in isolated areas through Alaska. This correspondence, however, should be regarded as a general one, without implication of exact time coincidence or precise analogy of formations; for the Cantwell formation and the Kenai, being throughout dominantly continental deposits, cannot be expected to display the degree of equivalence normal to marine deposits.

Origin.[1]—The character of the sediments composing the Cantwell formation signifies fluviatile continental deposition. The extensive development, number, and thickness of the conglomerate beds and the heterogeneous character of this rock indicate a source of supply under violent degradation, a short transport, and distribution by rushing waters competent to spread material of such coarseness. The presence, moreover, between the conglomerate members of carbonaceous mud rocks, carrying well-preserved plant remains in abundance and variety, implies areas of quiet deposition, such as swamps and small lakes, which alternately superseded, and in turn were transgressed by, zones of depositional activity. These conditions are afforded by voluminous streams emerging from a mountainous region on to a piedmont slope, intermontane valley, or shallow sea.

It is difficult with present information to decide whether the Cantwell was laid down as an interior continental deposit or upon the inland margin of a delta built out from a coast range of mountains. The apparent absence of deposits that might be attributed to the seaward portion of such a delta, the predominance of conglomerate over finer clastics, and topographic considerations incline the writer to favor the first explanation; although on this basis, for the preservation of the sediments from subsequent complete erosion, it must be assumed that downward warping in front of the mountain axis succeeded their deposition. That a compressive

[1] The interpretation of the origin of the Cantwell formation has been facilitated by a study of the contributions of Barrell on sedimentation, especially those appearing in *Jour. Geol.*, XIV (1906), 316–56, 430–57, 524–68; XVI (1908), 159–90, 255–95, 363–84; *Bull. Geol. Soc. Amer.*, XX (1909), 620; XXIII (1912), 377–46; and *Amer. Jour. Sci.*, XXXVI (1913), 429–72; XXXVII (1914), 87–109, 225–53. See also Mansfield, *Jour. Geol.*, XV (1907), 550–55.

earth movement followed deposition is clearly evidenced by the present folded character of the sediments.

The freshness and variety of the components of the conglomerate and finer sediments point to derivation from a region of rugged and youthful[1] topography under conditions of intense mechanical disintegration characteristic of a climate in which frost action played an important part. The presence of carbon and plant remains in the finer members of the formation indicates deposition under conditions unfavorable to oxidation, while the character of the plants themselves implies a temperate climate in the area of deposition, markedly milder than that of the region today, and in contrast also to the more rigorous conditions that prevailed in the high mountains from which the sediments were derived. The thickness and extent of the conglomerate members, moreover, seem to indicate a more vigorous precipitation than at present, capable of handling the abundant waste of the mountains. That this upland was the seat of active glaciation and consequently contributed glacial materials to the streams sweeping the Cantwell sediments downward is regarded as probable, though no observations can be adduced in support of this belief.

The presence of red sandstones toward the top, as noted by Brooks in the western portion of the formation, is not believed to have climatic significance;[2] for organic colors are conspicuous throughout that portion of the formation also. These members are rather suspected of expressing a variant in the lithology, or a change in the topography, of the source of supply.

The situation of the Tertiary land mass in reference to its basin of deposition cannot be given without reservation, but the present delineation of the Cantwell formation and the fact that its coarser members contain fragments of slate similar to that of older formations to the south and dissimilar to sediments exposed to the north suggest a position south of the present area of Tertiary rocks.

[1] See Willis, *Jour. Geol.*, I (1893), 478.

[2] Barrell (*Jour. Geol.*, XVI [1908], 293) observes that ". . . . red shales or sandstones, as distinct from red mud and sand, may originate under intermittently rainy, subarid, or arid climate without any close relation to temperature and typically as pluvial or fluvial deposits upon the land. . . . ."

THE PHYTOSAURIA OF THE TRIAS

MAURICE G. MEHL
University of Wisconsin

Some time ago the writer gave a brief notice of a new genus of phytosaurs of which *Angistorhinus grandis* Mehl was the type.[1] It is the purpose of this paper primarily to give a fuller description of this form and of another specimen mentioned in the above paper which further study has shown to be a new species of the same genus.

Angistorhinus grandis MEHL

The general characteristics of the specimen upon which this form is based were set forth in the previous paper and deserve but brief mention here. The skull is elongate with the rostrum produced into a long, slender, depressed snout and the nares elevated on a prominence at its posterior end. It is among the largest of the phytosaurian skulls, with a total length of about 977 mm. The squamosals extend a considerable distance beyond the posterior border of the quadrates and are produced downward into stout, hooklike processes. The supratemporal vacuities are closed posteriorly by a well-developed parieto-squamosal arcade that lies in the plane of the roof of the cranium. A marked depression is seen on the dorsal surface surrounded by the orbits and supratemporal vacuities. The irregular pitting of the surface is confined almost entirely to the lateral and posterior sides of the prominence upon which the nares are situated, and the flat dorsal surface of the cranium back of this, and in front of the supratemporal vacuities. In a lateral view the skull resembles that of *Mystriosuchus* Fraas[2] more than any of the other phytosaurs.

[1] *Jour. Geol.*, XXI (1913), 186.

[2] *Die Schwabischer Trias-Saurier nach dem Material der Kgl. Naturalien-Sammlung in Stuttgart zusammengestellt* (1896), p. 16, Pl. V.

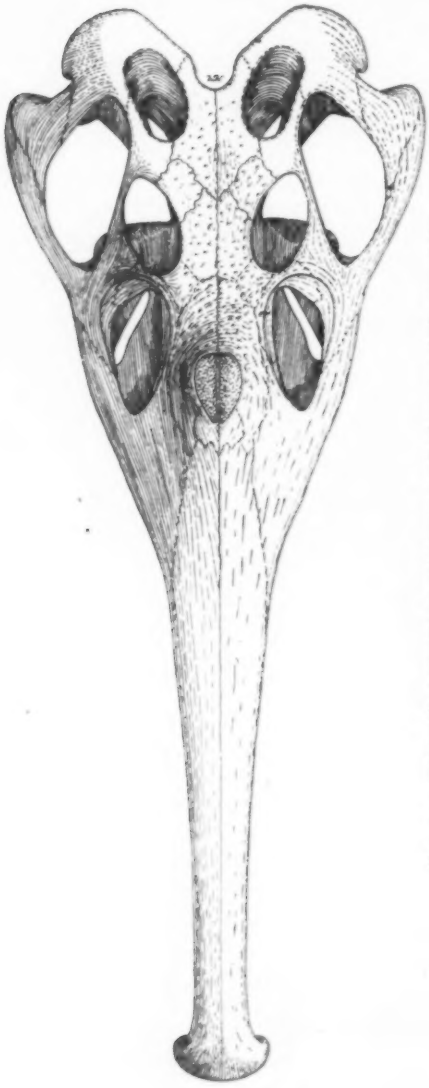


FIG. 1.—*Angistorhinus grandis*, dorsal view of skull, about one-sixth natural size

OPENINGS OF THE DORSAL SURFACE OF THE SKULL

The *external nares* are situated on a prominence at the beginning of the rostrum and rise fully 18 mm. above the level of the general surface of the cranial roof. The thin, vertical, median septum separating the nares does not rise to the same height as that of the posterior and lateral borders and thus the nares are given the appearance of a single opening with rounded posterior and acute anterior border. In length they are about 62 mm. and the greatest width of the seemingly common opening is 40 mm. The anterior border is about even with the anterior borders of the antorbital vacuities and 590 mm. from the tip of the rostrum. The region about the anterior border of the nares is somewhat abraded, and the sutures are not distinguishable. No septomaxillae have been distinguished, but as they are present in another specimen to be described later they probably have about the same position here and form the anterior border of the nares.

The *antorbital vacuities* are large, oval in outline, with rather acute anterior and posterior extremities. Their greater diameter is fully 130 mm. and the lesser diameter about 55 mm. Their size is accentuated by an abrupt depression or excavation of the bone along their posterior and upper borders.

The large *orbits* are somewhat elongate antero-posteriorly, about 89 mm. long and 55 mm. wide. Their planes are directed outward and a little less upward, perhaps. The interorbital width is about 68 mm. Only a narrow bar, not over 9 mm. in width, separates the orbit from the lateral temporal fenestrae.

The sides of the *lateral temporal fenestrae* form rough parallelograms with unequal diagonals. The greater diagonal is 171 mm. and the lesser, which is almost perpendicular to the plane of the palate, is about 113 mm. The greatest width of these openings is about 87 mm. There is an excavation for a short distance about their lower anterior borders similar to that of the upper posterior border of the antorbital vacuities.

The *supratemporal fenestrae* are oval in outline with an antero-posterior diameter of 84 mm. and a width of 46 mm. Their plane is directed upward. They are peculiar in that they are closed behind by a well-developed parieto-squamosal arcade that lies in

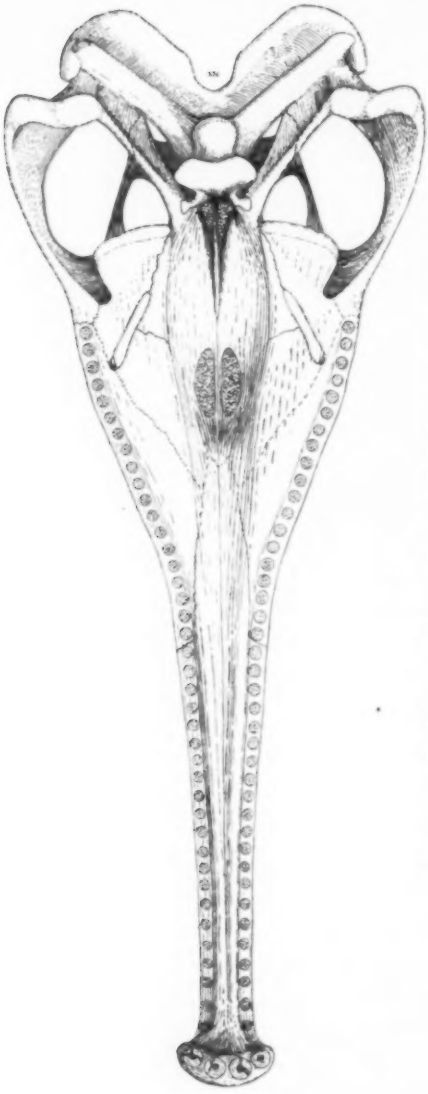


FIG. 2.—*Angistorhinus grandis*, ventral view of skull, about one-sixth natural size

the plane of the dorsal surface of the cranium. This will be discussed more fully in connection with the posterior aspect. No *parietal foramen* is present.

THE SEPARATE BONES OF THE DORSAL SURFACE

The *parietals* are united along the median line for a distance of about 100 mm. Posteriorly they are separated for a short distance by a deep, rounded notch. In spite of this deep incision, however, the occipital condyle is not visible in a dorsal view. Their anterior ends form an acute angle that separates the frontals for a short distance. The greatest width of the parietals, a little in front of the anterior border of the supratemporal fenestrae, is about 42 mm. for each element. The parieto-squamosal suture is not clearly distinguishable; apparently these elements meet on the inner posterior borders of the supratemporal fenestrae.

The *squamosals* form the posterior and half of the lateral borders of the supratemporal fenestrae and the upper posterior borders of the lateral temporal fenestrae. They are bent abruptly downward at a point on the antero-posterior line of the bar separating the supratemporal and lateral temporal fenestrae, the downward extension being produced into a hooklike process similar to that of *Mystriosuchus* but with greater development. These hooklike angles extend below the dorsal surface of the skull a distance of about 104 mm. This part of the squamosal and the lower posterior surface of the quadrate as well was weathered away, but a perfect natural mold in the matrix made possible a very accurate restoration.

The *postorbitals* form a part of the antero-lateral borders of the supratemporal fenestrae and the postero-lateral borders of the orbits. They extend down and forward to meet the upper posterior process of the jugal, and the two form narrow bars that separate the orbits and the lateral temporal fenestrae. The inner boundaries of the postorbitals are formed by the postfrontals and the parietals which meet near the middle of the postorbitals' length.

The *postfrontals* are rather small, approximately quadrangular elements that form the posterior half of the upper borders of the

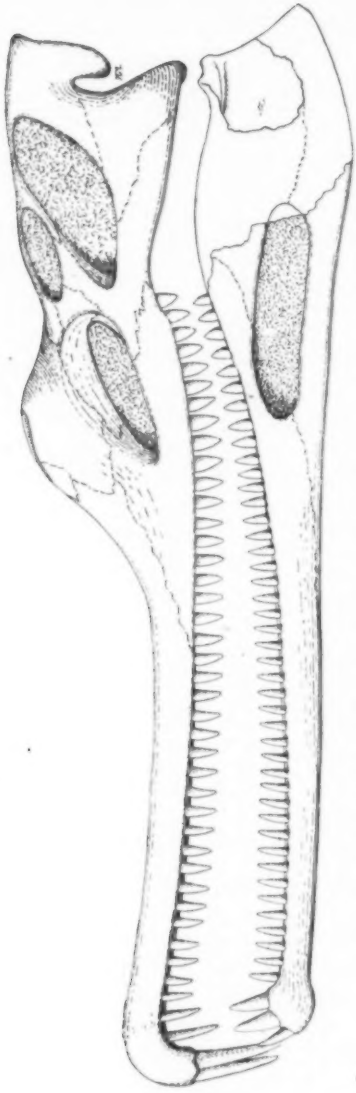


FIG. 3.—*Angistorhinus grandis*, lateral view of skull and mandible, about one-sixth natural size

orbits. They are bounded on the inner side from front to back by the frontals, the parietals, and the squamosals. The anterior sutures of the frontals are not evident.

The *frontals* appear to extend forward to within 68 mm. of the nares. This would give them a length along their median union of about 68 mm. They form the upper borders of the orbits and join the prefrontals and nasals in front. Their anterior margin seems to form a slight concavity into which the posterior ends of the nasals extend.

The *prefrontal* sutures are not certain; these elements seem to be small, approximately quadrangular in outline, and form the upper anterior borders of the orbits.

The *lachrymals*[1] unite with the maxillae to exclude the nasals from taking part in forming the borders of the antorbital vacuities. Their downward extent and union with the maxillae are uncertain.

The *jugal* forms the lower postero-lateral border of the skull. At its anterior end the jugal sends forward a splinter-like process that forms the lower posterior border of the antorbital vacuity. It also sends back from the anterior upper side a process that unites with the lachrymal in front and the postorbital behind, and thus forms the lower anterior border of the orbit and the anterior half of the lower temporal fenestrae boundaries.

The *quadratojugal* connects broadly with the jugal below. Its suture with the squamosals is not distinguishable. The sutures between the nasals, the septomaxillae, the maxillae, and the premaxillae cannot be determined with certainty. In all probability the relations are much the same as in another form to be described later (see Fig. 4).

The *premaxillae* are produced into a long, slender, subcylindrical snout much like that of *Mystriosuchus*. Viewed dorsally it tapers gradually from the cranium proper to a point near the extremity, from a width of 94 mm. at a distance of 140 mm. in front of the antorbital vacuity, to 47 mm. Near the tip the rostrum expands

[1] E. Gaupp has attempted to show that the so-called "prefrontal" of reptiles is homologus with the mammalian lachrymal and has suggested the name "adlachrymal" for the element previously called the lachrymal in reptiles (*Anatom. Anz.*, XXXVI, 1910). According to Gregory (1913), however, this homology is in nowise proven. In this paper the writer adheres to the old nomenclature.

gradually, attaining finally a width of 84 mm. The anterior extremity is bent abruptly downward and reaches a distance of 39 mm. below the plane of the ventral surface.

THE PALATE

Within the line of the alveoli on the ventral surface is a prominent rounded ridge on either side, as is noted in *Palaeorhinus bransini* Williston[1] and *Mystriosuchus*. It crowds close along the alveoli throughout the entire length of the premaxillae and gradually flattens

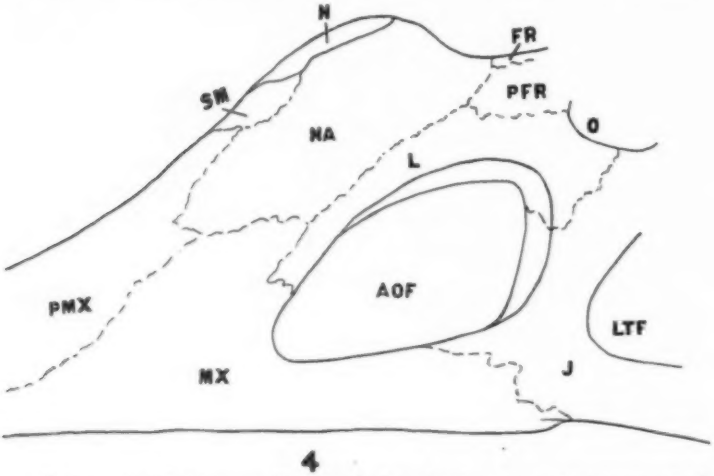


FIG. 4.—*Angistorhinus gracilis*, lateral view showing apparent arrangement of bones about the narial region, one-third natural size.

out on the maxillae. The teeth have all dropped from the alveoli except in the down-curved portion of the rostrum. Here four large ones are to be seen broken off close up to the premaxillae, two on each side. They are all round in section and measure about 15 mm. in diameter. If one may judge from a similar specimen in which these terminal teeth are preserved, they reached a length of from 80 mm. to 90 mm. or more in this form. In the premaxillae there are 23 alveoli on each side. These, with the exception of the two anterior ones described above, are approximately of one size, aver-

[1] J. H. Lees, "The Skull of Palaeorhinus," *Jour. Geol.*, XV (1907), 124.

aging about 11 mm. in diameter. The third tooth of the premaxillae series crowds close upon the down-curve portion of the rostrum. Back of this they are quite regularly spaced, averaging about 8 mm. between adjacent alveoli. A break across the rostrum near the maxilla-premaxilla union exposed an unerupted tooth very similar to that shown in Fig. 9.

The *maxillae* have their greatest extent along the lateral margins of the skull, where they reach a length of about 340 mm. They connect with the jugals near the middle of the antorbital vacuities and form the lower anterior borders of these openings. Above they

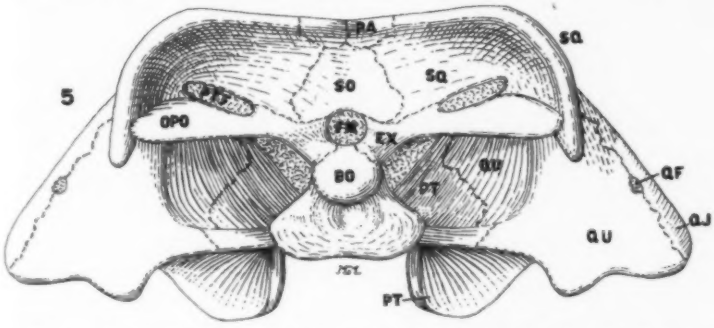


Fig. 5.—*Angistorhinus grandis*, posterior view of skull, two-sevenths natural size

connect slightly with the long anterior projections of the lachrymals and more broadly with the nasals. They contain about 19 alveoli each, of about the same diameter as those of the premaxillae. The spacing is much the same with the exception that in the posterior ones there is a slight diminution of the interalveolar space. Although little can be said with certainty concerning the crowns of the premaxilla-maxilla teeth, they probably ranged from those with nearly round sections, in the anterior part of the rostrum, to those that are laterally compressed with sharp, serrate anterior and posterior cutting edges. A great many of these sorts are found associated with the phytosaur remains and some of the laterally compressed ones were found in a fragment of a skull that very closely resembles the form here described. These teeth will be more fully discussed farther on.

The *palate* is somewhat crushed and distorted and most of the sutures are indistinguishable. Still a fairly good idea of its configuration and the general relations of the bones can be gained. It is quite highly arched along the median line and especially so in the region of the nares. The low, rounded arch along the median line of the premaxilla and maxilla, formed by the ridges parallel to the alveoli, increases gradually in height and width posteriorly, the increase being more rapid as the nares are approached, till at the posterior margin of the nares the arch is about 82 mm. wide at the general level of the palate surface and rises to a height of about 42 mm. from that plane. Behind this point the arch attains a still

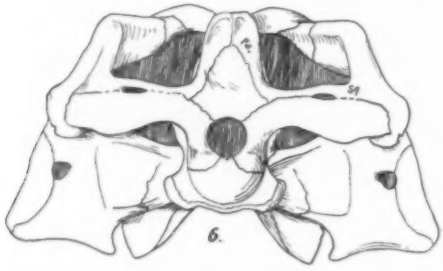


FIG. 6.—*Mystriosuchus planirostris*, posterior view of skull, two-sevenths natural size. Outlines and sutures after J. H. McGregor.

greater width before it again rounds in posteriorly. The internal nares are a little back of the external nares, 10 mm. perhaps. The forward ends of these openings are still covered by the matrix. Their exact extent in that direction cannot be told, but they are probably about 48 mm. long. The width between their lateral borders is 34 mm. The median partition is slightly wider on the palate surface than it is between the external nares. A line connecting the anterior borders of the *post-palatine foramina* crosses the internal nares a little in front of the posterior border. From this line the foramina extend back and inward a distance of 60 mm. They are about 8 mm. wide, are slightly curved, concave inward, and have rounded anterior and posterior borders. Their anterior extremities are 190 mm. apart and their posterior ends some 120 mm. In size they are similar to those of *Mesorhinus fraasi*

Jaekel,[1] a little larger, however, and more slitlike. In both of these forms the post-palatine foramina are considerably larger than in most of the other phytosaurs. The inter-pterygoid vacuity is notable in this form for its antero-posterior extent, being about 103 mm. long. It gradually diminishes in width from 35 mm., its greatest lateral extent, near its posterior boundary, to a very acute angle about 30 mm. back of the posterior border of the nares.

THE SEPARATE BONES OF THE PALATE

The posterior extension of the *premaxilla* is indeterminate; apparently it lacks quite a little of reaching the anterior border of the nares.

The *vomers* seem to have little lateral extent. The exact condition cannot be seen, however, as none of the boundaries is distinguishable. In all probability they unite broadly in front with the premaxillae and form most of the anterior border of the nares as well as their median borders. They probably do not extend as far back as the posterior end of the nares, certainly they cannot extend any considerable distance beyond.

Apparently the maxillae do not enter the nares at all. This is a condition suggested by Lees in *Palaeorhinus bransoni* (*op. cit.*, Fig. 2). If they do take part in the boundaries of these openings it is very slight and along the antero-lateral borders. The pterygo-palatine sutures are also more or less hypothetical.

The *palatines* reach far forward, forming most or all of the lateral borders of the nares. They seem to join the pterygoids posteriorly about the middle of the posterior palatine foramina. At the anterior ends of these openings they connect very slightly with the transverse (ectopterygoid) bones, if at all. On the general plane of the palate their greatest width is about 52 mm. along a line connecting the anterior ends of the posterior palatine foramina. At this width they are bent almost vertically upward in an antero-posterior direction.

The *pterygoid bones* form the walls and roof of most of the spacious palate arch back of the nares. Only a small triangular

[1] "Über einen neuen Belodonten aus dem Buntsandstein von Bernburg," *Sitzungsberichten der Gesellschaft naturforschender Freunde*, No. 5, Jahrgang, 1910, p. 209, Fig. 5.

portion of them is to be seen on the general plane of the palate surface. They seem to form the posterior half of the inner boundaries of the posterior palatine openings. Near the anterior limit of the basisphenoid they bend abruptly upward from the roof of the broadly rounded palate arch and extend above the parasphenoid. Anteriorly they approach each other till they embrace the para- and presphenoid and, still farther forward, close together below them. They meet the transverse bones broadly at the posterior ends of the posterior palatine foramina, the suture being directed backward from this point and a little inward. Posteriorly they close with ample and firm contact on the basi-pterygoid process. From this union the pterygoids send back and outward narrow processes which meet like processes of the quadrates about midway between the quadrates proper and the pterygo-sphenoid union. Their relations with the various elements seen in a posterior view will be discussed below.

The *transverse bones*, seen from below, present an approximately triangular outline. They form the lateral borders of the posterior palatine foramina and the anterior borders of the post-temporal vacuities. The broad pterygo-transverse sutures run back and inward from the posterior ends of the posterior palatine openings toward the basi-pterygoid process. Along the outer anterior side the transverse bones unite with the maxillae for a distance of about 40 mm. and at a somewhat less distance with the jugals. The postero-lateral corners are bent downward along a line running from their inner posterior angles obliquely outward from the direction of the posterior palatine openings and extend some 14 mm. below the general ventral plane of the skull.

The ventral surface of the *parasphenoid* is exposed the entire length of the inter-pterygoid vacuity and both the para- and the presphenoid are free from the matrix for some distance along one side. Their union is clearly indicated by a shallow longitudinal groove. At their union with the basisphenoid they form a thin, vertical plate which gradually thickens anteriorly very slightly and becomes rounded below. They are visible from below for a distance of 95 mm. Anteriorly at this distance, about 42 mm. back of the posterior border of the nares, the pterygoids meet below these

elements and hence their full anterior extent cannot be determined. At their point of disappearance, however, they still maintain their full thickness and must extend farther forward for some distance. Viewed from below, the postero-lateral processes of the sphenoid, the greater wings, form a high, transverse, rather sharp ridge slightly depressed at the middle and somewhat thickened at the extremities. This is about 76 mm. long and at the middle extends

FIG. 7.—*Angistorhinus grandis?* Cojoined basioccipital and basisphenoid, natural size.

down 44 mm. below the lower edge of the presphenoid. The anterior face of the pterygoid processes of the sphenoid reaches forward about 35 mm. from this ridge and extends down about even with it. These processes are quite stout and are separated from the posterior wings by a narrow but deep channel. The posterior part of the basisphenoid has been considerably abraded in this specimen and a portion of the occipital condyle is missing. Another specimen is present in the collection, however, a co-ossified basioccipital and basisphenoid (see Fig. 7) that resembles this form very closely, and this has aided materially in the interpretation of the specimen at hand. On the posterior side of the transverse plate formed by the

greater wings of the sphenoid is a circular excavation 26 mm. in diameter. Although shallow the depth of the excavation is accentuated by a prominent curved ridge on either side springing from the base of the occipital condyle.

THE POSTERIOR ASPECT

In a posterior view *Angistorhinus* resembles in the general form *Lophoprosopus*[1] (*Phytosaurus*) *kapffi* H. von Meyer[2] or *Mesorhinus Fraasi*. It is depressed in appearance as the skull is over twice as wide as high. From the lowest point of the quadrates to the plane of the dorsal surface it measures about 166 mm. Between the lower, lateral angles of the quadrates the width is about 386 mm. The post-temporal fenestrae are exceptionally large, perhaps larger than in any other form. Those in *Lophoprosopus kapffi* (see reference above) are about 32 mm., while in *A. grandis* they measure nearly 40 mm. The width is about 11 mm. From the outer extremities of these openings, which are about 180 mm. apart, they are directed inward and slightly down. The foramen magnum is smaller than in most of the phytosaurs, about 20 mm. in diameter. The quadrate foramina lie between the quadratojugal-quadrate union, about 46 mm. above the lower face of the quadrates. They are oval in shape, the vertical diameter being 23 mm., the lesser diameter about 11 mm. The outer border of these foramina is formed by the quadratojugals, the inner border apparently by the quadrate alone. One of the most remarkable features seen in the skull of *A. grandis* is the difference between this form and most of the other phytosaurian genera in the upper posterior border of the skull. In *Lophoprosopus*, *Mystriosuchus*, and other forms, perhaps, the parietosquamosal arcade, bounding the upper temporal vacuity posteriorly, is considerably reduced and depressed. Quoting McGregor on this point in *Mystriosuchus planirostris* Fraas:[3]

> A casual observation of the dorsal surface of the skull might lead the observer to think that the supratemporal fenestra was incomplete posteriorly,

[1] The substitution of *Lophoprosopus* for *Phytosaurus* is explained in the appended list of genera and species.

[2] McGregor, *Memoirs of the Amer. Mus. Nat. Hist.*, Vol. IX, Part II (1896), p. 45, Fig. 4.

[3] *Ibid.*, p. 46.

though its outer, anterior, and inner margins are normally represented by the highly sculptured squamosal, postorbital, and parietal. The median posterior portion of the parietal seems to end suddenly over the occiput, and the parieto-squamosal arcade appears to be lacking. In fact, Marsh has stated (1896) that "the skull of *Belodon* [*Phytosaurus*] shows that the supratemporal openings, characteristic of the true crocodillians are wanting."

Again, in characterizing the Phytosauria, McGregor says:[1] "Post-temporal (parieto-squamosal) arcade greatly depressed, reduced, and covered by muscles." In *Angistorhinus grandis*, however, this is not the condition. A comparison of the posterior view of *A. grandis* with that of *Mystriosuchus planirostrus* (Figs. 5 and 6) will serve well to show the differences. In the former the post-temporal arcade is well developed and borders the supratemporal vacuities in the same plane that extends over the roof of the cranium. The posterior extension of this parieto-squamosal arcade forms an overhanging shelf that in a dorsal view hides all the bones of the posterior side of the skull. The *parietals* seem to have a comparatively small lateral and downward expansion on the posterior surface and but slight contact with the supraoccipital. The squamosals, on the contrary, send down broad, platelike extensions from the posterior borders of the supratemporal vacuities that connect broadly with the supraoccipital at their inner edges. They form the upper and outer borders of the post-temporal vacuities and connect broadly with the upper inner ends of the opisthotics. As the specimen is now prepared, a large fenestra pierces this element on either side of the skull just over the post-temporal vacuity. This opening is, however, undoubtedly due to the abraded condition of the bone as the matrix beneath indicated an uninterrupted bone surface. The lateral, downward-directed angles or hooklike processes of the squamosals, mentioned above, extend some 23 mm. below the lower borders of the opisthotics. The boundaries of the supraoccipital are not distinct; it seems to be a small, approximately triangular element forming a considerable portion of the upper border of the foramen magnum. Its greatest width is probably not over 31 mm. The exoccipitals and opisthotics are thoroughly co-ossified. The *exoccipitals* form the lateral and probably most of

[1] *Ibid.*, p. 92.

the lower border of the foramen magnum. The part they take in the formation of the occipital condyle, I take it, is slight. The *opisthotics* are rather stout and widen considerably toward their lateral extremities. Just before they reach the hooklike processes of the squamosals their vertical measurement is about 38 mm. From this point they rapidly taper off in each direction. They form the lower and apparently the inner borders of the post-temporal vacuities. The relations of the *pterygoids* with the quadrates seem to be much the same as in *M. planirostris*, according to McGregor's interpretation. Their lateral extent on the posterior surface of the skull seems to be comparatively slight. There is no possibility of their taking part in the borders of the quadrate foramina as they do in *Belodon*[1] (*Mystriosuchus*) *plieningeri* H. von Meyer sp., according to F. von Huene.[2] In the specimen herein described the lower lateral portion of the quadrate was broken away, leaving, however, a good impression of the inner surface. From this and the natural mold in the matrix, of the outer surface, and with the aid of a separate quadrate found in the same locality, an accurate restoration was possible. It has an articular face of about 75 mm. lateral extent. There is an offset in the quadrate along a vertical line through the inner limit of this articular face. From this offset it extends toward the median line in a thin plate. Its inner edge meets the pterygoid and the two floor over a depression, the outline of which is a parallelogram with the greater diagonal directed upward and inward. This depression is bounded above by the opisthotic, on the outer side by the raised portion of the quadrate, below by the raised barlike portion of the cojoined quadrate and pterygoid, and on the inner side by the exoccipitals and the basisphenoid.

THE MANDIBLE

The mandible of this species is massive throughout. This is especially noticeable in the posterior symphysial region; here the

[1] For an explanation of the substitution of *Belodon* for *Mystriosuchus* see the appended list of genera and species.

[2] "Beiträge zur Kenntnis und Beurteilung der Parasuchier," *Geologische und palaeontologische Abhandlungen*, Neue Folge, Band X, Heft I (1911), p. 8, Fig. 3.

rami have a thickness of 40 mm. The smallest width of the mandible is 41 mm., at a point about 60 mm. back of the anterior end. From here the width increases gradually to about 90 mm. at the posterior end of the symphysis. The anterior end is considerably enlarged for the reception of the large terminal teeth. The greatest width of this expanded portion is 73 mm. The lateral margins are upturned so as to form a very conspicuous anterior-posteriorly directed groove along the median line. This is 31 mm. wide at the top and is broadly excavated to a depth of 9 mm. From the tip of the mandible to the posterior end of the symphysis the length is about 430 mm. The total length is about 930 mm. The external maxillary fenestra is about 200 mm. long and 44 mm. wide, with rounded anterior and posterior borders. Only the *alveoli* remain in the lower jaw upon which to base a description of the teeth. About 36 of these are present now on one side. There were probably 10 more present in the fragment which is now missing above the anterior end of the external maxillary fenestra, making about 46 alveoli in all. Three of these are placed in the expanded upturned anterior portion of the jaw. They are circular in section, as are all the alveoli, and greatly enlarged. The anterior one on each side is 12 mm. in diameter, the next two are of about equal size and measure 16.5 mm. in diameter. If the supposition that the tooth shown in Fig. 8 is one of these anterior teeth of this or a similar species is correct, we may assign a length of some 45 mm. or more to the teeth of the terminal expansion. The two anterior alveoli which are separated by the median channel mentioned above are about 24 mm. apart. Between the first and second and the second and third teeth only a thin film of bone intervenes. Between the last tooth of the terminal, enlarged series and the following one, the fourth, there is a space of about 15 mm. The alveoli back of the three large anterior ones vary considerably in diameter, ranging from 8 mm. to 16 mm. In a general way they increase in size posteriorly, but this is irregular, some of the largest being placed near the middle of the row. In consequence of this irregularity in the size of the alveoli there is an irregularity in the intervening spaces. These spaces range from a thin film to about 8 mm. in width, the greater spaces being, in general, in the anterior portion of

the mandible. This irregularity of size and spacing of the alveoli is probably largely due to the different ages of the teeth; that is, to loss and replacement of some. Well-developed, rounded ridges, such as are seen on the ventral surface of the rostrum, are present just within the lines of alveoli. In this specimen they are prominent anteriorly, combining near the anterior end and gradually spreading posteriorly. They become less prominent toward the posterior end of the symphysis and are entirely wanting before this point is reached.

The second specimen referred to in the preliminary notice of *Angistorhinus grandis*[1] would, it was hoped, when worked up, furnish a complete skeleton of that form. It was found, however, that the matrix was a hard, extremely tough sandstone and almost impossible to free from the bone, as the latter was in every case found to be softer than the matrix and extremely brittle. For these reasons a further attempt to prepare a skeleton has been abandoned, for the present at least. Aside from the skull, a portion of the posterior border of which is missing, and the lower mandible, which also lacks a little of the posterior extremities, only a single dorsal vertebra, several abdominal ribs, and quite an assortment of unassociated teeth are available for description. These serve well, however, to set the specimen off as a species distinct from *A. grandis*.

Angistorhinus gracilis SP. NOV.

This skull, which I take to be that of an adult individual, probably had a length of about 985 mm., somewhat greater than that of the specimen of *A. grandis*. The greatest length preserved, which does not quite include the quadrate, is 920 mm. This is somewhat greater than the same measurement of *A. grandis*, but in spite of this the latter is the more massively built skull, a point that is especially noticeable in the form of the mandible to be discussed farther on.

OPENINGS OF THE SKULL

The supratemporal fenestrae are missing, but from the close resemblance of the skull to *A. grandis* in other respects these open-

[1] *Jour. Geol.*, XXI (1913), 190.

ings were probably about the same in both forms. That is, the parietal-squamosal arcades are well devleoped and in the same plane as the dorsal surface of the cranium. The upper posterior border of the lateral temporal fenestra is also wanting. Its width of 80 mm., however, which is greater than that of *A. grandis*, would indicate at least an equally large fenestra in *A. gracilis*. Contrary to what might be expected from this greater width of the lateral temporal fenestra, the bar of bone left between it and the orbit is much more massive than in *A. grandis*. The orbits are somewhat smaller than in this latter genus, about 45 mm. wide and 75 mm. long. Some 30 mm. below the orbit, in the jugal bar, midway between the lateral temporal fenestra and the antorbital vacuity, is a large, well-defined foramen, probably for the enervation of the powerful cheek muscles as in the modern *Gavial*. This was not noted, but probably was present in the specimen representing *A. grandis*. The nares are elevated on a considerable prominence, about 31 mm. above the general level of the roof of the cranium. As in *A. grandis*, they are separated by a thin median partition that does not rise to the same elevation as the posterior and lateral borders of the nares. Thus the nares form, in a way, a common opening about 35 mm. wide and 55 mm. long. The exact length cannot be told, as the anterior borders are weathered away. The state of preservation is such that few of the sutures are distinguishable. Hence a description of all the separate elements of the skull is impossible. Special attention was paid to the region bordering the nares in the hope that the relations of the septomaxillary bones could be determined. With but a few exceptions the students that have worked with the phytosaurs have overlooked these elements. According to F. von Huene they are present in all of the phytosauria. To quote:[1] "Vor dem Nasenlöcher schliessen die Nasalia nicht zusammen. Hier tritt ein ungewöhnlicher Knocken, das Septomaxillare (bei allen Phytosauriern) dazwischen."

A diligent search on the specimen representing *A. grandis* and also *Palaeorhinus bransoni* failed to show these elements. However, one is forced to conclude that the failure to locate the sutures of such elements is due to the state of preservation of the specimen

[1] *Op. cit.*, p. 11. The reference is to *Belodon* (*Mystriosuchus*) *plieningeri*.

and not to their absence, as the septomaxillary bones are apparent in the specimen of *A. gracilis*. In all probability the region about the anterior border of the nares in many of the phytosaurs was always more or less cartilaginous. In many of the specimens that the writer has studied, either from figures or from the original, this anterior border is ill defined, extending forward in a sort of slit. In *A. gracilis* the septomaxillae evidently unite along the median line and form the anterior border of the nares. Their extent in front of the nares along this line is 45 mm. What part they take in the median septum in separating the nares cannot be determined. Their greatest width is about 27 mm. on a line through the anterior border on the nares. In front the premaxillae dovetail into them and form their anterior border. The nasals meet the premaxillae far forward along the lateral border of the septomaxillae and form the lateral boundaries of those elements. The relations of these various elements are diagrammatically shown in Fig. 4.

The rostrum in this species is much more slender than that of *A. grandis*. From the tip to the anterior border of the nares is a distance of 670 mm., or about 610 mm. to the anterior border of the antorbital vacuity. In *A. grandis* these measurements are 650 mm. and 585 mm. respectively. The width of the rostrum just back of the terminal expansion is 34 mm., at about midlength 44 mm., and at a point 140 mm. in front of the antorbital vacuity, 56 mm. These respective measurements in *A. grandis* are 42 mm., 65 mm., and 94 mm. In the latter species the rostrum, seen in a lateral view, tapers down much less abruptly from the cranium proper than in the former. The terminal expansion of *A. gracilis* starts abruptly at a distance of 68 mm. from the end of the horizontal portion, increasing from a width of 34 mm. to 51 mm. This width it maintains, with only a very slight increase, to the tip. The extremity is bent abruptly downward and extends approximately 44 mm. below the ventral surface of the rostrum. The rostrum as a whole is curved, concave upward, but this is probably a result of deformation. As seems to be the usual case in phytosaurian remains, most of the teeth have dropped from the alveoli. Only the first, second, and fourth of the right premaxilla teeth are preserved in this specimen but these are entire and well preserved.

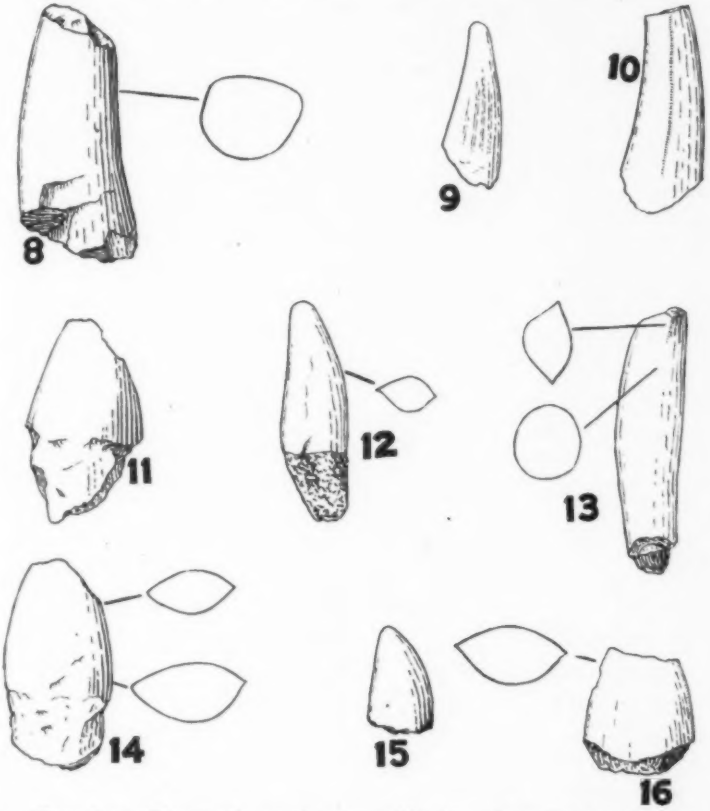
The first and second are in the down-curved tip of the rostrum. The fourth is probably the last of the long rakelike teeth, for it is the last tooth in the anterior expanded portion. The first tooth, the anterior one, is nearly complete, about 35 mm. long and 9 mm. in diameter at the base. This is probably a substitute for an earlier tooth, as the section of the corresponding tooth on the opposite side, which is broken off close up to the surface of the rostrum, indicates a tooth as large as those that follow. The second tooth is considerably larger and still preserves the sharp point. It is 78 mm. in length and has a diameter of 12 mm. at the base. The third tooth is broken off at the base but the section indicates a size for it equal to the fourth. This tooth is 60 mm. long and 9 mm. in diameter. The section of all of these anterior teeth is round with no indications of trenchant edges or fluting. The space between these teeth of the expanded anterior portion is somewhat greater than those between the remaining teeth. Between the two anterior teeth is a space of fully 18 mm. Between the first and second, the second and third, and the third and fourth the spaces are approximately 12 mm., 9 mm., and 10 mm., respectively. The number of teeth in the rostrum back of these cannot be told accurately. It is probably slightly greater than in *A. grandis*, however, as there are about 38 in the space from the tip to the anterior border of the antorbital vacuity in the former and 34 in the space of the latter. This is inclusive of those of the expanded anterior portion. In *A. gracilis* the alveoli back of the expanded portion are subequal, averaging about 10 mm. in diameter, and all are round. There is a slight increase in diameter from the anterior end of the series backward. The spacing is rather irregular, varying between 4 mm. and 9 mm. While the crowns of none of these posterior teeth are preserved in place, they can be described with some degree of certainty. From the locality where the skulls herein described were collected nearly all the vertebrate remains were phytosaurian. Many loose teeth were picked up as well as several associated with skulls. There is no group of animals from this locality other than the phytosaurs to which the teeth can be ascribed with certainty. A selected series of these teeth is shown in Figs. 8–16. One specimen (not here figured), a fragment of a skull in which some of the

teeth of the margin below the antorbital vacuity are still preserved, forms a part of the collection. This fragment is undoubtedly *Angistorhinus* sp. The crown of one of these teeth is well preserved and is almost identical with that shown in Fig. 16, which is one of several teeth found loose in the matrix close to the skull of *A. gracilis*. The crown of this tooth is 25 mm. long, 20 mm. wide at its greatest width, which is just above the alveolus, and at this same point has a thickness of about 12 mm. The anterior and posterior edges are sharp and very finely serrate, there being three serrations to one millimeter. Of the other teeth figured all but that in Fig. 9 have sharp anterior and posterior cutting edges with serrations numbering from fifteen to twenty in five millimeters. In that one, while the anterior and posterior edges are not sharp, the section is oval and it is further differentiated from the others by indications of fluting. In general it resembles the unerupted tooth seen in a section through the rostrum of *A. grandis* mentioned above. Just where this tooth found its place in the dentition cannot be told. It is the presumption, however, that it is one of the anterior teeth. While the ends of any series that can be formed of these teeth differ widely, they grade into each other in such a way that one would probably not be justified in supposing that such a series could not be found in the jaws of a single individual. Fig. 8, for instance, might well be the anterior tooth in the lower jaw of *A. grandis;* Fig. 10 is much the same sort of a tooth, but somewhat smaller. Fig. 12 is probably one of the premaxillary teeth, Figs. 11, 14, and 16, the middle or posterior maxillary teeth, and Fig. 15, one of the last in the series. The sections of Fig. 13 show well how the approximately circular root suddenly expands into the trenchant edged crown. Such variations as those above show the uncertainty encountered in basing species on a few isolated teeth with our present fragmentary knowledge of the dentition of these forms.

THE MANDIBLE

The posterior extremity of each ramus is missing, probably about 200 mm. The part present shows the same characteristics as does the skull when compared with *A. grandis*, viz., a greater length and more delicate build. The length of the symphysis is approximately 500 mm., considerably greater than in *Belodon*

(*Mystriosuchus*) *plieningeri* or *Lophoprospus* (*Belodon kapffi*). In these two latter forms, according to F. von Huene,[1] the length is 290 mm. and 280 mm. respectively. The end of the mandible swells rapidly at a point about 51 mm. from the tip into a disklike expansion with a width of some 68 mm. This terminal expansion



FIGS. 8–16.—Phytosaurian teeth, presumably from the genus *Angistorhinus*. Figs. 8 and 10, teeth of the anterior terminal expansion of the lower jaw? Fig. 9, probably one of the anterior premaxillary teeth. Figs. 11, 14, 15 and 16, posterior maxillary teeth? Fig. 12, probably one of the anterior premaxillary teeth. Fig. 13, root and part of crown of one of the posterior teeth, showing the sudden transition from round to compressed section. All a little under natural size.

[1] *Op. cit.*, p. 27.

differs from that of *A. grandis* in that the upper surface is a plane instead of being deeply grooved along the median line. Below the expansion there is a considerable convexity for the accommodation of the roots of the large terminal teeth. Just back of the expansion the mandible measures 29 mm. and has a thickness of about 17 mm.

Posteriorly the width increases gradually to 99 mm. at the posterior end of the symphysis or about 9 mm. more than the same measurement in *A. grandis*. It measures 25 mm. in thickness at this point, while this measurement is 41 mm. in *A. grandis*. These differences of measurement of the posterior end of the symphysis may be partially due to crushing in the former specimen but there is little evidence of this. Of the lower jaw none of the teeth is complete; the few that remain are broken off close up to the mandible and add little to our knowledge of the dentition except as to the relative size and spacing of the teeth. The alveoli are all more or less circular in outline but vary somewhat in size. In the expanded portion of the anterior end are placed three large teeth of approximately equal sections. They are apparently antero-posteriorly compressed, but this is probably an oblique section, a horizontal section through an outward-directed tooth. The average antero-posterior diameter is about 10 mm., considerably less than that of *A. grandis*. The two anterior teeth are separated by a space of 24 mm., while the other teeth of the expanded portion are crowded close together. The four teeth of the down-turned extremity of the rostrum evidently met close in front of the lower mandible, thus causing its large terminal teeth to close three on either side of the rostrum. The alveoli immediately back of the expansion are considerably smaller than the anterior ones and somewhat smaller than the teeth in the same region of *A. grandis*. They average about 5 mm. in diameter and are separated by a space of about 6 mm. From 4 mm. they increase quite regularly to 8 mm. or 9 mm. in the posterior ones and all are approximately 6 mm. or 7 mm. apart. In this species the teeth of the lower mandible are more numerous than in *A. grandis*, about 49 on each side.

THE VERTEBRAE

The single vertebra freed from the matrix is a little distorted and has lost the upper part of the spine but it shows the essential

features well. It is a dorsal vertebra, one of the most anterior. It corresponds in a general way with those of the same region in *Rhytiodin carolinensis* Emmons and may therefore be compared with one of the anterior thoracics of that form figured by McGregor.[1] The vertebra of *Angistorhinus gracilis* is considerably the larger and the proportions are somewhat different. The centrum is very much constricted laterally, measuring but 29 mm. in the middle. The posterior face of the centrum is approximately circular, measuring about 54 mm. in diameter. The transverse diameter of the anterior face is somewhat greater than the vertical diameter, due to the enlarged articulation for the tuberosity of the rib. These diameters measure 68 mm. and 69 mm. respectively. The diapophyses form heavy transverse processes extending horizontally at the level of the neural canal and expanding distally. They are approximately triangular in section with one vertex directed downward. The centrum is considerably excavated below the base of the diapophyses, leaving them supported for a short distance laterally by two thin buttresses which are confluent below with the anterior and posterior rims of the centrum. The capitular articulation (if it be the true articular surface) is slightly concave. The articulation for the tuberosity is low down on the anterior border of the centrum, is convex, and as large as the capitular articulation. The posterior zygopophyses are missing. The anterior zygopophyses have a considerable anterior prominence. They are large, are directed up and inward at an angle of about 45° from the horizontal, and, though this measurement may be exaggerated by distortion, measure 44 mm. between the center of the articular faces. The spine is broken off about 31 mm. above the neural canal. The total height of the vertebra must have been at least 150 mm., however, and probably more. The following table of measurements will serve to show some of the differences in the two forms:

	Rhytidodon carolinensis	*Angistorhinus gracilis*
Length of centrum	38 mm.	45 mm.
Height of centrum	42 mm.	54 mm.
Total height	120 mm.	(at least) 150 mm.
Width across diapophyses	104 mm.	156 mm.

[1] *Op. cit.*, p. 66, Figs. 15, 15*a*, and Pl. 8, Figs. 10, 10*a*.

VENTRAL RIBS

Weathered out about the specimen were many fragments of ventral ribs. Several of these ribs have been restored and all show a length of 260 mm. or more. Most of them are almost straight for half their length, whence they curve gently to the extremity. At the middle they are somewhat flattened, having greater and lesser diameters of about 16 mm. and 12 mm. respectively. They taper slightly to the extremities and here the section is almost round. These are probably lateral ribs of the ventral series. One of the ribs differs considerably from the others in the amount of curvature. It is broadly curved at the center with the extremities bent nearly at right angles. This is possibly one of the median ventral series.

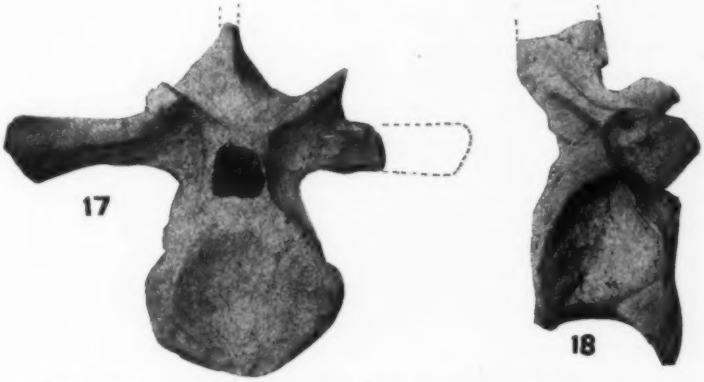
COMPARISON OF *A. grandis* AND *A. gracilis*

A brief review of some of the salient features of these two specimens will serve to show the distinctness of the two species:

1. Terminal expansion of rostrum taking place gradually and increasing in width to the tip.	1. Terminal expansion of rostrum taking place suddenly and retaining the same width to the tip.
2. Rostrum 94 mm. wide at a point 140 mm. in front of the antorbital vacuity.	2. Rostrum 56 mm. wide at a point 140 mm. in front of the antorbital vacuity.
3. Terminal expansion takes place in front of third tooth.	3. Terminal expansion takes place in front of fifth tooth.
4. Greatest length of skull is 977 mm.	4. Greatest length of skull is about 985 mm.
5. Length from anterior border of orbits to tip of rostrum 755 mm.	5. Length from anterior border of orbits to tip of rostrum 750 mm.
6. Interorbital width 68 mm.	6. Interorbital width 68 mm.
7. Terminal expansion of lower jaw upturned along lateral margins to form a median antero-posterior grove.	7. Terminal expansion of lower jaw in a plane.
8. Rounded ridges along inner side of alveoli prominent.	8. Rounded ridges along inner side of alveoli not prominent.
9. Number of teeth in lower jaw about 46 on each side.	9. Number of teeth in lower jaw at least 49 on each side.
10. Diameter of alveoli of lower jaw, exclusive of the large anterior ones, ranging between 8 mm. and 16 mm.	10. Diameter of alveoli of lower jaw, exclusive of the large anterior ones, ranging between 5 mm. and 8 mm.

A COMPARISON OF THE GENUS *Angistorhinus* WITH OTHER GENERA

Angistorhinus is one of the largest forms known. The skull is longer than any other except perhaps that of *Lophoprosopus* (*Belodon*) *kapffi*. The most striking difference seen between these two forms is in the rostrum. In *Lophoprosopus* there is a high, vertical swelling or crest extending almost the entire length, while in *Angistorhinus* the rostrum is low and slender. In this form, too, the anterior extremity is abruptly turned down, much more so than



FIGS. 17–18.—*Angistorhinus gracilis*, anterior and lateral views of one of the anterior thoracic vertebrae, about one-third natural size.

in *Lophoprosopus*. Another important difference is seen in the well-developed parieto-squamosal arcade lying in the plane of the dorsal surface of the cranium of *Angistorhinus* and the much-reduced, depressed post-temporal arcade of *Lophoprosopus* that gives the supratemporal fenestra the appearance of being open behind.

From *Mystriosuchus* the genus differs, not only in the development of the post-temporal arcade in the manner mentioned above, but also quite radically in the teeth. In *Mystriosuchus* there are 94 of these in the upper dentition and not more than 84 in the upper dentition of *Angistorhinus*. In the latter genus, as pointed out above, the posterior teeth are laterally compressed with sharp

anterior and posterior cutting edges. In the former genus, on the other hand, as shown by Dr. E. Fraas,[1] all the teeth are circular in section. In *Angistorhinus* the anterior end of the rostrum is much more abruptly down-turned and the downward extent is considerably greater than in *Mystriosuchus*. In the former genus, too, the posterior palatine foramina are much longer and more slit-like. In a lateral view the cranium proper of *Angistorhinus* is seen to make up a greater portion of the entire length of the skull than is the case in *Mystriosuchus*.

Rutiodon, of which *R. carolinensis* is the type, probably resembles *Angistorhinus* in general form more than any of the other genera. The differences found in the vertebrae have been pointed out above and it was shown that those of *Angistorhinus* were considerably the larger. The skulls, too, bear out this difference in size. The total length has not been determined for *Rutiodon* but the indications are that it was about that of *Mystriosuchus*, viz., 820 mm.,[2] while that of *Angistorhinus* is from 977 mm. to 985 mm. or more. The distance from the anterior border of the nares to the tip of the rostrum in the former is 510 mm.; in the latter genus the same measurement is 590 mm. Although a direct comparison of the dentition of the two forms is impossible, the teeth of *Rutiodon* at the middle of the rostrum seem to be considerably larger than those of *Angistorhinus*. The post-temporal arcade of the latter is greatly developed (in this it seems to differ from all other genera except perhaps *Palaeorhinus*) and the posterior palatine foramina are quite different. In the former genus they are almost round and probably not over 15 mm. in diameter, while in *Angistorhinus* they are about 60 mm. long and about 8 mm. in diameter.

Besides the much more anterior position of the nares in *Palaeorhinus* and the but slightly down-curved tip of the rostrum, this form differs from *Angistorhinus* in that the skull is much smaller and the slender rostrum makes up but about one-half the entire length. *Palaeorhinus* also has a less backward extension of the upper posterior border of the skull, much less developed "squamosal hooks," and the opisthotics are less massive, thinner, and more spatulaform than in *Angistorhinus*. The anterior extent of the

[1] *Op. cit.*, p. 16. [2] McGregor, *op. cit.*, p. 58.

pre- and parasphenoid and of the inter-pterygoid vacuity is apparently considerably less in the former genus, and the pterygoid process of the basisphenoid is less massive and more separated from the greater wings than in the latter. The number of teeth in the upper mandible of *Palaeorhinus* is about 72, while in *Angistorhinus* they number 84. In all probability the post-temporal arcade is somewhat the same in both forms. Of this more will be said later in the special reference to *Palaeorhinus*.

The anterior part of the rostrum of *Mesorhinus fraasi* is missing. The rostrum therefore affords little material for comparison. What remains of it, however, suggests a form between *Angistorhinus* and *Lophoprosopus*. The external nares are much more anterior in *Mesorhinus* than in *Angistorhinus*, and the former, according to Jaekel, possess a parietal foramen. There is also apparently a difference in the elements about the anterior border of the nares in the two forms. Jaekel says:[1]

> Zwischen den vordern Enden der Nasenlöcher stehen zwei vertikale schmale Knochenleisten, die ich unbedenklich als Teile der Prämaxillaris angesprochen haben würde, wenn nicht Herr v. Huene ähnliche Gebilde bei anderen Belodonten eben als besondere Elemente, als Septomaxillaria beschrieben hätte.

F. von Huene, however, in a later paper, considers these as the ends of the premaxillae.[2] If we accept the interpretation of the latter, the difference between the two forms in this respect is evident. In *Angistorhinus* the septomaxillary bones seem to unite in the median line in front of the nares and exclude the premaxillae from that opening, while the premaxillae of *Mesorhinus* supposedly form the anterior and much of the lateral borders of the nares. While the parieto-squamosal arcade seems to be developed somewhat similar in the two forms, if one may judge from the figures of *Mesorhinus*, its posterior extent is not so great in the latter.

Palaeorhinus bransoni WILLISTON

This genus and species was briefly described by Dr. S. W. Williston in 1904.[3] In 1907, after a detailed study of the type specimen, Mr. J. H. Lees published a much fuller description of

[1] *Op. cit.*, p. 201. [2] *Op. cit.*, p. 50. [3] *Jour. Geol.*, XII (1904), p. 696.

this form. Several new features were presented in this paper. To quote:

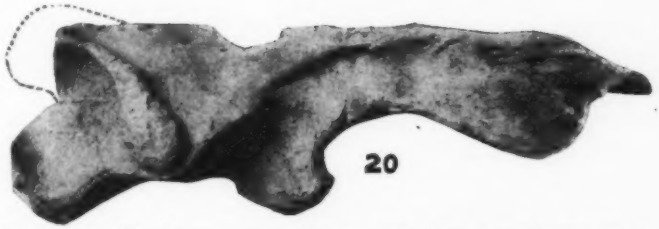
> The new features which the present study has disclosed may be here summarized: The presence of the otic capsule and its relations and dimensions have been delineated. The sutural relations of the palatines, pterygoid, and vomer have been more clearly delineated and the unsuspected posterior extension of the latter elements as far as the presphenoidal vacuity demonstrated.

And again (p. 147):

> In *Mystriosuchus* the parietals extend backward between the supratemporal openings at the level of the top of the skull for a little less than one inch, while in *Palaeorhinus* they extend in this direction two and one-fourth inches, are widely separated as already described, and meet the squamosals posteriorly to inclose the supratemporal at the upper level of the skull.

With these particular things in mind, viz., the posterior extent of the vomers, the otic opening, and the parieto-squamosal arcade, the writer has made a careful examination of the material representing this form. The skull is very much crushed, especially the palate, and few of the sutures are discernible. As the specimen is now prepared the articular face of the quadrate is turned almost directly outward instead of down, thus greatly exaggerating the posterior width of the skull. Basing the outline of a posterior view of *Palaeorhinus* on either *Mystriosuchus* or *Angistorhinus*, the greatest width would probably be not over 240 mm. in an uncrushed condition, or but little if any greater than that of *M. planirostrus*. In 1911, in a paper cited above, Jaekel mentioned the peculiar relations and development of the vomers in *Palaeorhinus* and presented figures showing what he considered a more likely interpretation of the palate. Jaekel's interpretation is certainly more phytosaurian. However, with the present state of the specimen one can only say that it is probably not justifiable to consider the vomers as extending back and forming the anterior border of the "presphenoidal vacuity." Concerning the otic capsule little can be said. The opening is present on the right side of the specimen; the left side is restored. This region was restored in *Angistorhinus grandis* from the impression of the inner surface of the bone. A thin film of the bone was still present and showed no indications of such an opening. Indeed, to the writer's knowledge, *Palaeorhinus*

is the only form in which the opening has been noted. In conversations with him, Dr. Williston has expressed the opinion that the opening is accidental in this case. One should probably not lay too much stress on its presence in this form till it has been found in other members of this genus. The parieto-squamosal arcade is crushed and largely broken away, giving an appearance to the supratemporal fenestra much like that of *Mystriosuchus planirostrus*. Whether this is the true condition or whether the form is like



FIGS. 19–20.—Ilia of a new, unnamed form. The ilium shown in Fig. 19 was referred by Lees to *Palaeorhinus bransoni*. Both figures about one-half natural size.

that of *Angistorhinus* as described above is not certain. The writer is inclined to agree with Lees, however, in assigning to it the form of the latter, but this view should probably also be held as tentative.

It has been impossible to ascertain the association of the ilium figured with the skull of *Palaeorhinus*.[1] Material has recently come into the hands of the writer which shows that the ilium is not that of *Palaeorhinus* as Mr. Lees supposed, but belongs to an entirely different group of reptiles. Fig. 19 is of the same ilium figured with

[1] Lees, *op. cit.*, Fig. 8.

Palaeorhinus, with slightly different orientation to bring out its similarity with another specimen, Fig. 20. This second specimen is somewhat crushed laterally and is slightly smaller and more slender than the first. They probably represent two different species but the figures indicate that they are generically the same, or at least should be so considered till evidence to the contrary is forthcoming. A brief notice of this new form follows:

NEW GENUS?

The material upon which this form is based consists of several extremities (both proximal and distal) of limb bones, several vertebrae from various regions of the body, and many other fragments, besides the ilium figured above (Fig. 20). The specimen is a part of the collection of the University of Chicago expedition of 1904 and comes from the Popo Agie River region of the Trias of Wyoming.

One of the vertebrae has been freed from the matrix and shows characteristics not at all like those of the phytosaurs. It is a middle or anterior thoracic vertebra with the capitular articulation in a transitional stage in its elevation from the centrum to the arch. The centrum is spool- or hourglass-shaped with anterior and posterior faces slightly concave and is much constricted laterally along its midlength. It is 54 mm. long and 10 mm. wide at the center (this width is probably lessened by pressure). The articular faces are slightly oblong in outline, about 32 mm. wide and 39 mm. high. The diapophyses are in the form of thin horizontal plates confluent anteriorly with the articular faces of the zygapophyses and widening regularly posteriorly. Suddenly, near the posterior ends, they thicken below into the articulation for the tuberosity. At this point the diapophyses are about 56 mm. from tip to tip. They are supported at the posterior end by two thin diverging buttresses, one directed toward the upper posterior articular face of the centrum but not reaching this point, the other confluent with the capitular articulation on the upper anterior articular face of the centrum. The distance between the articular faces for the tuberosity and that of the capitulum is some 30 mm. The total height of the vertebrae is 96 mm. The upper portion of the spine is

missing, however—probably no small portion. At the base the spine is thin, not over 5 mm. in thickness, and has a width of 43 mm.

Several forms have been described from the region where these remains were found, all based on more or less fragmentary material.[1] The indications all point to their distinctness from the form herein described, but as yet not enough is known to warrant its being given a new generic name. The writer expects soon to make a series of thorough collections in the western Trias and hopes to add to the knowledge of this and other forms that are little known. A fuller description of the material here mentioned and a discussion of its relationships will follow.

All who have worked with the phytosaurs have felt, I am sure, that we have been too zealous in our efforts to place all the fragments that have been referred to this group in the various schemes of classification. Too often we have proposed new species and even new genera for a few tooth fragments or a few imperfect limb bones.

The following list consists of those forms that, in the writer's opinion, have been fairly well established. In the arrangement of these forms no attempt is made to show the genetic relationship.

1. *Phytosaurus Jaeger*[2]

P. cylindricon Jaeger

In 1861 H. von Meyer attempted to show that *P. cylindricon* and *P. cubricon* Jaeger were in reality described from different regions of the jaw of one individual and that this form was the same as his *Belodon kapffi*.[3] This being the case, the name *Phytosaurus* has priority, and McGregor has so used it (1906) referring to that genus the forms that had previously been placed in the genus *Belodon*. The material upon which the genus *Phytosaurus* was based, however, is in such an exceedingly poor state of preservation

[1] For a description of *Dolichobrachium gracile* Williston, *Eubrachiosaurus browni* Williston, and *Brachybrachium brevipes* Williston, see *Jour. Geol.*, XII (1904), 688–94.

[2] G. F. Jaeger, *Über die fossil Reptilien welche in Württemberg aufgefunden worden sind*. Stuttgart, 1828.

[3] "Reptilien aus dem Stubensandstein und Keuper," *Palaeontographica*, VII 253–346.

that one can never safely refer other material to it.[1] The species *P. cylindricon*, then (the form first described), is the type and only species of this genus, and the form described by von Meyer as *Belodon kapffi* should be considered distinct.

2. *Belodon* von Meyer

B. plieningeri von Meyer

B. (*Mystriosuchus*) *rutimeyeri* F. von Huene

The genus *Belodon*, of which *B. plieningeri* is the type, was proposed in 1842[2] for a form with a slender rostrum and laterally compressed, arrowhead-shaped posterior teeth.

3. *Mystriosuchus* E. Fraas

M. (*Belodon*) *planirostris* H. von Meyer

This form differs from the genus *Belodon* chiefly in that the teeth of the former are all round in cross-section.

4. *Rutiodon* Emmons[3]

R. carolinensis Emmons

R. manhattanensis von Huene

The writer has followed McGregor in uniting in the first species most of the many specimens that have been described from the Trias of the eastern United States under the following names:

Clepsysaurus pennsylvanicus I. Lea.
Centemodon sulcatus I. Lea.
Omosaurus perplexus J. Leidy.
Palaeosaurus sulcatus E. Emmons.
Palaeosaurus carolinensis E. Emmons.
Compsosaurus priscus J. Leidy.
Clepsisaurus leaii E. Emmons.
Eurydorus serridus J. Leidy.
Belodon carolinensis E. D. Cope.
Belodon priscus Cope.
Belodon lepturus Cope.
Belodon leaii Cope.
Rhytiodon rostratus O. C. Marsh.
(?) *Beldon validus* Marsh (doubtful, never figured).

[1] Although the writer has not seen this material, he has been informed by no less an authority than Dr. S. W. Williston, who has recently had the opportunity to examine the type remains, that the preservation is such that one can in nowise be certain of its generic identity.

[2] Von Meyer, *Neues Jahrb. f. Mineralogie.*

[3] Geological report on the midland counties of North Carolina.

5. *Lophoprosopus* gen. nov.
   L. (*Belodon*) *kapffi* von Meyer
   (?) *L. buceros* Cope[1]

The generic value of the form represented by *Belodon kapffi* von Meyer is well established. The name *Lophoprosopus* is here substituted because, as pointed out above, both *Belodon* and *Phytosaurus* are preoccupied.

In the past several species have been based on very doubtful material and referred to the group represented by *L. kapffi*. These deserve, perhaps, brief mention here:

Belodon (*Zanclodon*) *arenaceus* E. Fraas, a fragment of a mandible that resembles *L. kapffi* and may well belong to that species.

Belodon ingens E. Fraas, a single skull very similar to that of *L. kapffi* and probably the same.

Belodon scopax E. D. Cope. Judging from the snout this form may well belong to the genus *Palaeorhinus*.

Belodon superciliosus E. D. Cope. This species is based on a few skull, teeth, and scute fragments and is very doubtful.

Heterodontosuchus ganei F. A. Lucas. The fragment of a mandible upon which this species was based was originally described as a Triassic crocodile. According to McGregor[2] we may expect to find this to be identical with *L.* (*Phytosaurus*) *buceros* when better material is at hand.

6. *Palaeorhinus* Williston
   Palaeorhinus bransoni Williston
   (?) *P. scopax* (see the reference to this species under the genus *Lophorhinus*)

7. *Angistorhinus* Mehl
   A. grandis Mehl
   A. gracilis Mehl

[1] Some question arises as to whether this form belongs here. To quote Dr. O. Jaekel (*Sitzungsberichten der Gesellschaft naturforschender Freunde*, No. 5, Jahrgang 1910, pp. 219–20): "Durch die Gesamtform des Schädels, besonders die Vorwölbung des pränasalen Schnauzenteils, die weit rückwärtige Lage der Nasen und die weite Vorstreckung der Squamosa-Ecke ist diese Form im Rahmen der *Phytosauridae* so deutlich gekennzeichnet, dass ich für sie daraufhin einen neuen Gattungstypus vorschlagen, und ihm den Namen *Metarhinus* geben möchte."

It is probably well to refer this form tentatively to the genus *Lophoprosopus* till further discoveries settle the point.

[2] *Op. cit.*, p. 94.

8. *Mesorhinus Jaekel*

Mesorhinus fraasi Jaekel

9. *Parasuchus* Lydekker

P. hislopi Lydekker

Doubtful genera and species:

Rylea platyodon E. von Huene gen., Riley and Stutchbury sp.

These few imperfect remains, consisting of incomplete limb bones, teeth, caudal vertebrae, etc., are in all probability phytosaurian, but the material seems to be too meager to receive a generic or even a specific name.

Episcoposaurus E. D. Cope

E. horridus E. D. Cope

E. haplocerus E. D. Cope

Little is known of either of these two forms and their reference to the phytosaurs is not entirely warranted.

The genus *Palaeochtinus*[1] Cope, under which were described *P. appalachianus*, *P. orthodon*,[2] and *P. dumblainus*,[3] was based on a few teeth that Cope took to be those of a large dinosaur. These resemble closely some of the teeth figured with *Angistorhinus* and other phytosaurs and may well be phytosaurian remains.

Incertae sedis:

Steganolepis robertsoni T. H. Huxley

While the fragmentary remains that represent this form may indicate their phytosaurian affinity, the relationship is not at all clear. In view of our meager knowledge of this form and also *Mesorhinus*, it hardly seems advisable at this time to remove the latter form from the *Phytosauridae* and place it with *Steganolepis* in the family Steganolepidae as F. von Huene has suggested.[4] Probably undue stress has been placed on the presence of a parietal foramen in *Mesorhinus*. Only a single incomplete and poorly preserved skull has as yet been found. This fact being considered, it would seem that the presence of the parietal foramen is in nowise definitely established.

[1] *Proceedings Amer. Philos. Soc.*, 1877, p. 182.

[2] "A Preliminary Report of the Vertebrate Paleontology of the Llano Estacado," *Geol. Survey of Texas, Fourth Ann. Rept.*, 1892, p. 15, Pl. 2, Fig. 1.

[3] *Ibid.*, p. 16, Pl. 2, Figs. 4–6.

[4] *Op. cit.*, p. 50.

The writer wishes to take this opportunity to express his appreciation for the privilege of studying the material in the University of Chicago collections and also to thank Dr. S. W. Williston for his generous aid.

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THE ORIGIN OF THE INCLUSIONS IN DIKES

SIDNEY POWERS
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PART II

(*C*) *Many inclusions have risen.*—

Shelburne Point, Vermont: On Shelburne Point and on Nash's Point, near-by, a few miles south of Burlington, Vermont, are several inclusion-bearing dikes of great interest. They have been described by Hitchcock[1] and by Kemp and Marsters.[2] On both sides of Shelburne Point are outcrops of a 20-foot bostonite dike filled with angular inclusions of Middle Ordovician shale and red Cambrian quartzite. These inclusions have sharp edges and do not appear to have been noticeably altered by the bostonite. On Nash's Point is another bostonite dike, about 12 feet wide and vertical, with chilled margins 2 feet and 1 foot wide on the respective sides of the dike, and a mass of fragments in the middle. A part of the fragments are quite angular and a part decidedly rounded. They vary in size from a fraction of an inch to 4 or 5 inches in length, but Kemp and Marsters found one piece of norite 18 feet in diameter. They consist of garnetiferous hornblende schist, pre-Cambrian norite, quartz, grey sandstone, red Cambrian sandstone, Trenton shale, and black limestone, cemented by a bostonite groundmass. Kemp and Marsters add: "Under the microscope, sections of norite show plagioclase and garnet, all exhibiting the results of dynamic action. Sections of the red quartzite have the usual fragmental character, with the evidences of strain less developed." The presence of the norite and schist inclusions show that the dikes have come through an indefinite amount of the pre-Cambrian as well as through Cambrian sandstone and Ordovician limestone into

[1] "On Certain Conglomerated and Brecciated Trachytic Dikes in Vermont," *Proc. Amer. Ass. Adv. Sci.*, XIV (1860), 156.

[2] "Trap Dikes of the Lake Champlain Region," *U.S. Geol. Surv., Bull. 107.*

their present position in Middle Ordovician shales. On the end of Nash's Point a 10-foot sill of bostonite is filled with unaltered shale inclusions from the immediate walls.

Kemp and Marsters have the following suggestions to offer concerning the manner in which the dikes acquired the inclusions:

> Two explanations may be offered for this rock. One, that it has been intruded in a line of previous faulting and attrition, which has broken up the walls and left loose material to be gathered up by the intrusive magma. This explanation has the greater weight with the writers. The other is that it represents only the upper portion of a dike and thus contains the float material which the advance of an intrusive body, that forced its own passage, would naturally gather from its walls. The lack of such inclusions in the neighboring dikes may be due to the fact that their tops have been eroded.

The difficulty with the first explanation is that there is no evidence of any faulting with brecciation at the particular places where the dikes came up. Moreover, how did the sill which follows a sharp fold in the shale obtain its inclusions by this hypothesis? It would appear extraordinary for faulting to occur in both a vertical and nearly horizontal position (the shales having a low dip) and to have brecciation occur only in these particular cases. The second explanation is partly in accord with the theory about to be proposed, but there is no reason why these should be the top of the dikes, or why the dikes for some distance vertically should not be equally filled with inclusions.

The origin of the inclusions appears to the writer to have been the shattering of the walls of the dike by the intrusive magma as it ascended through the pre-Cambrian, Cambrian, and Ordovician. Little corrosion could take place in fragments caught in such a magma and shot upward to their present position where they would be quickly chilled because of the inadequate supply of heat and lack of time. The invaded rocks would be comparatively cold when ripped off, and would therefore have a chilling effect upon the surrounding dike-magma in a 20-foot dike. Kemp and Marsters found the bostonite to be porphyritic, with a fine groundmass showing flow-structure around the inclusions. The rounded character of some of the inclusions is probably due to mechanical causes, principally the friction of the blocks against the walls of the dike

and against each other in ascent. The thickness of the sedimentary series in the region is about 12,000 feet from the top of the pre-Cambrian to the horizon of the outcrop of the dike. Hence, the pre-Cambrian norite inclusions must have risen over two miles and their edges would be necessarily rounded.

The abundance of the inclusions in two dikes and a sill, while other near-by dikes of the same composition and age do not show any inclusions at the present exposure, is not sufficient evidence to prove that all of the dikes do not contain inclusions in place. The shattering of the walls of some of the dikes may have been a purely accidental phenomenon, due to the way in which the fissures formed through which the magma came. If the passage were through a vertical fissure with straight unbroken walls, no inclusions would be expected.

Mancos, Colorado: Professor Kirtley F. Mather, of Fayetteville, Arkansas, has kindly contributed the following account of the inclusions in dikes near Mancos, Colorado:

In the San Juan region of southwestern Colorado, about 8 miles southwest from the town of Mancos, there is a small area of igneous rock which is locally known as "the Blow-out." The Mancos River at this point is flowing in a steep-sided youthful valley cut through the Mesaverde formation, which caps the neighboring plateaus, and far into the Mancos shale. "The Blow-out" is situated high up on the eastern slope of the valley in the midst of the maturely dissected shales. It consists of a conical mound about a quarter of a mile in diameter and two or three hundred feet in height, composed of mediosilicic extrusive volcanic material, flows, tuffs, and breccias. Cutting the volcanic cone and the surrounding country rock there are several subsilicic dikes which vary in width from an inch to 4 or 5 feet. The more prominent of these dikes can be traced for many hundred yards outward beyond the boundary of the central cone. Both the extrusive and intrusive rocks contain an abundance of inclusions of several different types of rock materials.

The extrusive volcanic rock varies considerably in its composition in different parts of "the Blow-out," but typically it is an andesite consisting of plagioclase feldspar, about $Ab_{55}An_{45}$, accompanied by biotite, magnetite, and augite, imbedded in a glassy matrix. The dike rock likewise is quite variable in composition, but it consists essentially of phenocrysts of biotite, augite, olivine, and plagioclase, imbedded in a groundmass of glass, pyroxene, felty plagioclase, magnetite, and biotite. The percentage relations of the minerals in the phenocrysts is notably different in different parts of the same dike, but usually the rock is rich in biotite and poor in plagioclase. The latter is little, if any, more calcic than that in the extrusive rocks.

Inclusions in the dike-rocks are extremely numerous and vary in size from tiny fragments up to masses nearly 3 feet in length. They consist of rounded, subangular, or occasionally angular, fragments of shale, sandstone, granite, metamorphosed limestone, and quartzite conglomerate. The inclusions of sedimentary rock are relatively abundant in approximately the same proportions as those in which the shales, sandstones, limestones, and conglomerates occur in the underlying sedimentaries—the Mancos shale, the Dakota sandstone with its basal conglomerate, the McElmo and LaPlata formations, etc. In the thicker dikes, shale inclusions are more numerous near the contact walls than toward the middle of the dike. The inclusions of sedimentary rocks are evidently fragments from the walls of the conduits through which the lava passed upward and from which they were torn by some process analogous to stoping. They all show the effects of their immersion in the molten mass with which they were surrounded.

The origin of the granitic inclusions is less apparent. No granites are known to outcrop within the drainage basin of the Mancos River, which includes much of the LaPlata Mountains northeast from Mancos. It is believed, however, that their origin must be similar to that of the other inclusions in the same dikes, and hence it is inferred that beneath the sedimentary rocks which outcrop in this region there must be a body of granite which was likewise cut by the dikes and from which fragments were torn by the ascending lavas in the same manner as those from the overlying strata. Such a granite mass might be either an intrusion into the sedimentaries, preceding the vulcanism, the effects of which are now displayed at the surface, or it might be a hill of pre-Cambrian or Paleozoic rock around and above which the Mesozoic sediments were laid down. These inclusions of igneous rock display a remarkable selective assimilation by the dike-magmas of certain of the minerals of the granite. This will be discussed in a paper now in preparation.

Aschaffenburg, Germany: In the Spessart region near Aschaffenburg there are a number of lamprophyre dikes, some of which contain inclusions of granite or of minerals derived from an augen gneiss. In the Schweinheimer kersantite dike, Thürach[1] has found inclusions 40 cm. in diameter, of a granite which contains orthoclase augen 5 cm. in length. Goller[2] has described quartz and orthoclase inclusions from similar dikes. The quartz fragments are rounded, and have a maximum length of 10 mm. The orthoclase fragments are less abundant and have a maximum length of 6 cm. These inclusions are scattered through the dikes. They

[1] "Über die Gliederung des Urgebirges im Spessart," *Geogn. Jahreshefte*, V (1893), 101.

[2] "Die Lamprophyrgänge des südlichen Vorspessart," *Neues Jahrb. f. Min.*, Beilageband VI (1889), 521 ff.

have come from the same underlying gneiss as the granite fragment. The selective action of the dike-magma in including fragments of only quartz and feldspar from the underlying gneiss is comparable to the case at Mancos. This fragmentation is favorable to the contention of Day, Sosman, and Hostetter[1] that the shattering of a siliceous rock is due principally to the expansive force of quartz at the inversion point of 575°C.

Somerville, Massachusetts: In Somerville and Medford, Massachusetts, are a number of exposures of diabase dikes, among which the Medford dike and the dikes of the Mystic River quarry carry inclusions. These dikes have variable mineralogical compositions. The Medford dike cuts Cambridge slate (probably of Permian age) and the older igneous complex of the Middlesex Falls. It varies in width up to 270 feet, and is probably over 4 miles in length. The Mystic River dikes cut the Cambridge slates, and are less than 10 feet in width. The inclusions in these dikes are chiefly composed of aggregates of single minerals, with vein quartz predominating. They are usually less than 6 inches in diameter and have well-rounded surfaces. Some of the quartz inclusions are fully 2 feet in diameter. A list of the inclusions found in the Medford dike includes[2]: quartz-diorite pegmatite, granite, graphic granite, diorite, quartzite, quartz schist, slate, quartz, feldspar, hornblende, and apatite. The inclusions in the Mystic River quarries are: altered biotite granite surrounded by a secondary rim of finer granite which has recrystallized with more femic constituents, diorite, pegmatite, quartzite, quartz, andesine feldspar (Ab_4An_3), hornblende, biotite, magnetite, apatite, zircon, and graphite.

The quartz inclusions are of especial interest and have been described by T. A. Jaggar, Jr.[3] These fragments have an irregular, clastic form. Sometimes the edges are rounded and sometimes very angular, with frequent embayments from magmatic corrosion.

[1] "The Determination of Mineral and Rock Densities at High Temperatures," *Amer. Jour. Sci.* (4), XXXVII (1914), 1–39.

[2] In making out these lists the writer has looked through the collections made by Professors Jaggar, Woodworth, and Palache, and is indebted to them for permission to publish the results.

[3] "An Occurrence of Acid Pegmatite in Diabase," *Amer. Geol.*, XXI (1898), 203–13.

A narrow-necked embayment, 3 inches in depth in the end of an inclusion 1 foot in length and 3 inches in width, has been noted by Jaggar. The quartz inclusions all appear to be surrounded by a wreath of augite prisms about 1 mm. wide, characteristic of quartz inclusions in basalt. This endomorphic reaction rim was found by Jaggar to consist of four zones between the diabase and the quartz: (1) diabase feldspar, (2) augite crystals, (3) potash feldspars, (4) micropegmatite.

The inclusions in these dikes appear to have been principally derived from rocks underlying the Cambridge slate. Very coarse diorite pegmatites, specimens of which have been found at Kidder Avenue in the Medford dike, and quartz veins seem to have furnished most of the material for the inclusions, the fragments of rocks being quite scarce, as would be expected in normal dikes shattering a few blocks off their walls during their ascent. The diorite pegmatite is not exposed in the vicinity of the dikes unless it is the same as that described by Jaggar near Arlington Heights.

These inclusions may have floated up in the dike-magma or they may have been forced up by it. Day *et al.* (*op. cit.*) have shown that the density of diabase glass is 2.763 and therefore heavier than the mineral xenocrysts. Whether the latter were formed by the differential expansion of the various minerals, a theory whose importance is emphasized by Goldschmidt,[1] or whether they were formed by purely mechanical action, is not clear. Numerous small xenocrysts of quartz and feldspar, from the vein quartz and diorite pegmatite, are found throughout the diabase, at least part of which have been broken off the corners of the inclusions.

Quartzose inclusions appear to be corroded frequently in igneous masses. A number of cases of reaction rims around quartz inclusions in extrusive rocks will be found described by Lacroix.[2] In the Globe district, Arizona, intrusive diabase contains numerous inclusions of vein quartz which are conspicuously corroded and embayed and surrounded by reaction rims of amphibole.[3] The

[1] *Die Kontaktmetamorphose im Kristianiagebiet* (1911), pp. 107–9.

[2] "Les enclaves des roches volcanique," *Annales de l'Académie de Mâcon*, X (1893).

[3] *U.S. Geol. Surv., Geol. Atlas*, Globe Folio (No. 111), 1904. Other diabase intrusions are described which contain many inclusions which have sunk.

Firth of Forth, Scotland, quartz diabases owe their free silica to solution of acid country rocks in normal diabase and contain corroded quartzose inclusions.[1]

Ogunquit, Maine: About 2 miles south of Ogunquit, Maine, several inclusion-bearing sills are exposed on the seashore halfway between Perkins Cove and Bald Head. The rocks of the region consist of thick-bedded slates, tilted into a vertical position with a uniform northeast strike, cut several miles inland by biotite granite. The slate is intruded by vertical trap sills of two or three generations, the older ones being porphyritic. The sills are mostly 5 feet or less in width, but one is over 50 feet wide. Most of the inclusion-bearing sills are of this older porphyritic type, which is seen under the microscope to be an augite-biotite kersantite. The sills occasionally cut across the bedding of the slates. They are younger than the frequent quartz veins which cut the slate.

In many of the sills in the vicinity there are a few inclusions. The latter are often 6 to 8 inches in length, with their longer axes parallel to the sides of the sill. In one sill, 2 feet, 10 inches wide, are two rounded inclusions of coarse graphic granite about 16 and 12 inches in diameter respectively, an angular block of granite 16 inches long and about 3 inches wide, with smaller subangular fragments of quartz and granite. There is a fused contact around all these inclusions. A 7-foot sill contains in one place many small subangular and rounded fragments of quartz, granite, syenite, and slate.

The principal inclusion-bearing sill is exposed for about 400 feet, showing a variation in width from 3 to 5 feet. It runs parallel to the stratification and has resisted erosion by the sea, while the slates on one side have been eroded away. The sill is cut by two younger dikes.

The character of the inclusions varies greatly. They are composed, in order of relative abundance, of a moderately coarse-grained light-colored syenite with green hornblende as the dark constituent; a coarse-grained granite resembling the syenite but containing free quartz; fine-grained pink and white aplitic granites which are probably biotite granites; fine-grained syenite seen in

[1] E. Stecher, *Tschermak's Mitt.*, IX (1888), 193.

thin section to consist principally of microperthite and oligoclase feldspars, with chlorite and other alteration products and a few grains of quartz; slate similar to the slate adjoining the sill; and vein quartz evidently derived from the veins which cut the slate. The size of the inclusions ranges from a few inches to 4 feet in length, in various parts of the sill. Thus, the inclusions in the part shown in the left-hand section of Fig. 1, where the sides of the sill are chilled, have an average size of 8 inches long by 4 inches wide. Nearer the sea, the margins of the sill do not show chilling, as

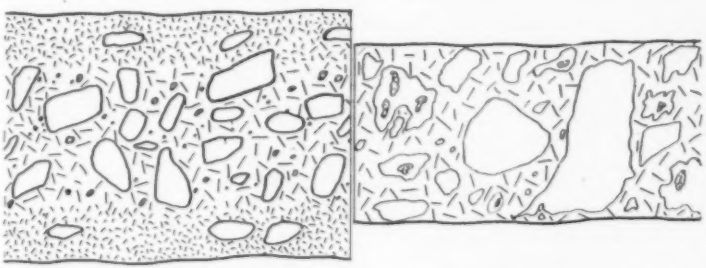

FIG. 1.—Two portions of the inclusion-bearing sill at Ogunquit, Maine. In the left-hand section the walls of the sill are chilled and the fragments show fused contacts but not resorption. In the right-hand section—about 100 feet away—the inclusions are being resorbed and their edges are indistinct. The width of the sill in the right-hand section is $3\frac{1}{4}$ feet.

shown in the right-hand section of Fig. 1, and here the average length of the fragments is about 1 foot. In the first area the inclusions have subangular to rounded outlines and tightly sealed contacts. In thin section the quartz from the aplitic granite can be seen to have migrated a sixteenth of an inch into the labradorite-augite-biotite matrix of the sill, but the feldspars from the coarse syenite have not migrated. In the second area, the inclusions all have corroded margins and the keratophyre may be seen to have worked its way into the coarsely crystallized syenite and granite. Blocks of the pink aplitic granite 3 and 4 feet long respectively and about $1\frac{1}{2}$ feet wide, with their longer axes orientated in some cases perpendicular to, and in other cases parallel to, the walls of the sill, where the latter is $3\frac{1}{4}$ feet wide, show that they have been

subjected to high temperature for a long period of time, as long tongues of granite run out into the dike-rock. In other cases merely remnants of inclusions over a foot in diameter are left, the greater part of the volume of the original block being filled with keratophyre mixed with the feldspars from the inclusion.

The origin of the inclusions of the igneous rocks must have been at some distance below the present exposure. No brecciation of the slate is observable at the surface, so it is thought that the inclusions of slate, which are often 2-foot cubes, and quartz, which are always small, also came from some depth, but not from such a distance as the igneous rocks. It is not known to the writer whether syenites, aplitic granites, and graphic granite outcrop farther inland or not. At Wells, 7 miles to the north, biotite granite is quarried.

The manner in which the inclusions of igneous rock, and possibly those of slate and quartz, were obtained is apparently by shattering, probably along the walls of the feeders of the sills. The resorption of the edges of the blocks must have been begun in depth where there was sufficient heat to assimilate a large part of an originally cubical block over 1 cubic foot in volume. However, as pointed out in other cases, if these blocks were shot up to their present position, the resorbed edges would be worn off; if they floated up, the resorbed edges would be partly preserved. Therefore, it is necessary to assume that the temperature of both the inclusions and the sill was nearly the same and that the corrosive action continued for some time after the blocks were at about their present levels, due to an additional supply of heat from below. This hypothesis is supported by the fact that where the margins of the sill are chilled, the inclusions in the marginal zones and also the more abundant inclusions in the center of the dike show fused contacts, but not extensive resorption. On the contrary, where there are no chilled margins, indicating that this part of the dike remained hot longer than the rest and then consolidated at one time, the inclusions all show resorption and assimilation and only skeletons are left of some of them. As the sill is of aschistic composition, such heating action is thought to be possible.

Rossland, British Columbia: During the C2 excursion of the International Geological Congress last summer, an inclusion-

bearing dike was observed by the writer at Rossland, British Columbia. The dike, which is known locally as the "White Dike," is 6 feet in width and consists of a mass of large bowlders imbedded in an augite kersantite matrix. Two types of bowlders were observed in the outcrop; one a white, fine-grained rock which was mistaken in the field for a quartzite, the other a bluish-grey rather coarse-grained rock with many small dark-brown patches. The texture of both is gneissic. A microscopic examination has shown that both types are anorthosite, the former consisting almost entirely of labradorite ($Ab_{40}An_{60}$), the latter of similar labradorite with small amounts of pyroxene, probably an orthorhombic variety with positive optical character. The pyroxene has in part altered to biotite and chlorite. Magnetite occurs in small amounts in both specimens. They both show the effects of some dynamic movement.

FIG. 2.—An exposure of the "White Dike" at Rossland, British Columbia, showing the abundance of inclusions. The sketch has been traced from a photograph. The scale is given by the width of the dike, which is 6 feet.

The inclusions vary in size, as shown in Fig. 2, the larger being 1 to 2 feet long. In shape they are partly angular, but in one of the surface exposures they are subangular or well rounded and do not have sharp edges, nor do the edges show any effect of corrosion. The inclusions weather out of the matrix, but slightly fused contacts are shown in the weathered material. The dike-rock consists of basic andesine or labradorite and augite phenocrysts in a matrix of labradorite, augite, biotite, and some magnetite.

The dike is in the extreme western portion of the Rossland district, about 5 miles north of the international boundary. It is shown on the Candian Geological Survey map of Rossland, at the western edge of the map, outcropping in a cut of the Great Northern Railway and at a flume 1,000 feet to the northwest. It cuts porphyritic monzonite in the first outcrop and augite porphyrite in the second. It has also been found in the 900-foot level of the Josie

mine, and it there presents the same appearance as on the surface and in the upper workings.[1] A similar dike has been found in the Columbia-Kootenay mine, but the inclusions are not as large as in the "White Dike."

The sedimentary rocks of the region consist, according to the map of the Boundary Creek mining district, of Paleozoic sediments, some of which are metamorphic, and Tertiary conglomerates and tuffs. The igneous rocks are of a number of types and represent several periods of intrusion. Gneisses of questionable age occur in the region, but no anorthosite has been reported.

Three explanations may be offered for the immediate origin of the inclusions:

1. The dike-magma may have come through a thick series of conglomerates of Paleozoic age and carried the pebbles and bowlders upward, dissolving their cement.

2. The dike-magma may have intruded Tertiary conglomerates, which have since been removed by erosion, the bowlders sinking in the molten dike-rock.

3. The dike-magma, when at some distance beneath the surface may have shattered off blocks of the rocks through which it passed, and carried them upward together with the blocks shattered in the formation of the fissure. The friction of the numerous inclusions against each other and against the walls of the dike would remove the angles and give the blocks rounded outlines.

These possibilities will be discussed in order.

1. If there were a thick series of conglomerates in the Paleozoic sediments, they should be exposed somewhere in the region, yet there are no conglomerates mapped in the surrounding 200 square miles (Can. Geol. Surv. Map No. 828). That the conglomerates would have to be of great thickness to furnish so many bowlders is shown by the known extent of the dike: 1,000 feet in length and 900 feet in depth.

2. If the dike had procured its inclusions from a Tertiary conglomerate, now largely eroded, there appears to be no good reason why a large majority of the inclusions should consist of a dynam-

[1] This information was kindly furnished by Dr. Charles W. Drysdale, of the Canadian Geological Survey.

ically metamorphosed rock which is not exposed at the surface. In the Boundary district there occur Tertiary tuffs and conglomerates overlain by basalts and other lavas, the bowlders as well as the matrix of these tuffs and conglomerates being largely of igneous origin. The conglomerates were apparently only locally developed, their formation being preceded and succeeded by volcanic activity.[1] The relative age of the dikes and the Tertiary sediments is not known.

3. The third theory involves shattering along the walls of the dike, the fragments being rounded during their ascent in the dike-rock. The explanation as to why the inclusions (so far as the writer is able to judge from the specimens collected) consist largely of anorthosite must lie in an unusual amount of shattering accompanying the formation of the dike-fissure in that very compact rock, while little shattering occurred in the younger intrusives which may still have been at a high temperature. It is certain that the presence of several million inclusions under the conditions described calls for extraordinary conditions.

The material which has been removed from the inclusions appears in part in the hand specimen of the kersantite as white xenocrysts of varying size. In the field these xenocrysts are not noticed, on account of the weathered condition of the rock. It is also probable that many of the feldspar phenocrysts—and perhaps even some of the pyroxene phenocrysts—of the kersantite are really xenocrysts of the anorthosite.

Little Belt Mountains, Montana: In the Little Belt Mountains Pirrson has described some minette dikes which have brought up masses of a plutonic rock from some depth below the surface.[2] One of the inclusions is a mica syenite, 2 to 3 feet in diameter. The minette does not show the least amount of endomorphic modification, but retains its normal minerals and structure to the contact. Pirrson writes: "From this we may infer that the mass was taken up while the magma was extremely hot, and that it had acquired very nearly the temperature of the fluid mass before the latter

[1] R. W. Brock, "Preliminary Report on the Rossland District," *Can. Geol. Surv.* (1906).

[2] *U.S. Geol. Surv., 20th Ann. Rept.*, Part 3, p. 536.

began crystallizing." The syenite has been somewhat altered by mineralizing vapors from the magma.

The sapphire-bearing Yogo dike also contains inclusions.[1] This mica-trap dike cuts Madison limestone. It is from 3 to 6 feet wide and is vertical. The dike walls are rough, but not especially irregular, and have been slightly indurated by the intrusion. In some places the upward termination is seen, as shown in Fig. 3. The fragments are angular and consist of limestone and shale from the Madison and underlying terranes. In the main excavations a similar breccia is shown at the surface, but the size and number of the fragments decrease with depth.

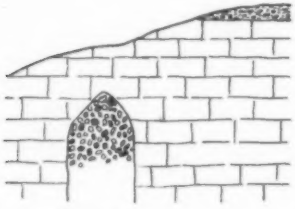

FIG. 3.—Section of upper limit of sapphire-bearing dike, wall of Yogo Canyon, Montana. The inclusions are limestone and shale fragments from the fissure walls, which have floated up to the top of the dike. (After Weed.)

The fragmental material has evidently been shattered from the fissure walls and floated upward as the molten rock rose in the fissure. The Yogo dike is the only case presented in this paper where the inclusions are proven to have floated up to the top of the dike. From the diminution in the number of inclusions with depth, it is evident that if the dike were exposed only at a lower level, few if any inclusions would be shown. On the other hand, inclusions are rarely present at the upward termination of dikes, or, if present, they have not been mentioned in the descriptions.[2]

Syracuse, New York: A few inclusion-bearing peridotite dikes at Syracuse, New York, have been described by several writers. The country rock is of Salina (Silurian) age. The inclusions are largely of Paleozoic rocks, but some are of pre-Cambrian gneisses. The latter are usually more rounded than the former, the result of the attrition involved in their upward journey.[3] In one dike

[1] W. H. Weed, *U.S. Geol. Surv., 20th Ann. Rept.*, Part 3, p. 455.

[2] Suess in *Das Antlitz der Erde*, Vol. III, Part 2, p. 658, describes several dikes the tops of which are exposed, but the above is the only one in which inclusions are mentioned.

[3] C. H. Smyth, Jr., *Amer. Jour. Sci.* (4), XIV (1902), 26.

which is 6 feet in width there are long, narrow inclusions of the country rock, one of which is 15 feet in length and about 1 foot wide with tapering ends. The thickness of the sedimentary rocks in the region is probably about 4,000 feet, and through this distance the pre-Cambrian inclusions have come.

Near Ithaca there are about 25 peridotite dikes, some of which contain a large number of shale and limestone inclusions from the country rock (of Upper Devonian age) and from the underlying Paleozoic sediments.[1] Similarly in the peridotite dikes of Elliott County, Kentucky, there are inclusions of acid (pre-Cambrian?) rocks.[2]

Crazy Mountains, Montana: On the south side of Cottonwood Creek in the Crazy Mountains, Montana, are two elliptical stock-like masses of ouachitite breccia cutting flat-lying Fort Union, Eccene, shales.[3] The masses are 750 feet apart. The lower one is 200 feet long and 40 feet wide, the upper one 300 feet long and 200 feet wide. In each case the contacts are vertical and the igneous masses are jointed in both a horizontal and a vertical direction, the joints cutting both inclusions and cement. The fragments consist largely of fine-grained granitic gneiss, feldspathic quartzite, black slate, and granite. The outline of the fragments is subangular to angular. The interesting feature of these breccias is that the gneissic granite must be of pre-Cambrian age, as no such rock is exposed in the petrographical province. The thickness of the sedimentary series underlying the Crazy Mountains[4] is 24,000 feet, consisting of 4,500 feet of Algonkian, 3,900 feet of Paleozoic, 100 feet of Juratrias, and 15,500 feet of Cretaceous and Eocene strata. Therefore, the gneiss inclusions have apparently risen vertically for a distance of over 4 miles.

The origin of the inclusions was probably by thermal combined with mechanical shattering, as the magma has ascended in elliptical intrusions, replacing the country rock. The circulation in the

[1] *U.S. Geol. Surv., Geol. Atlas*, Folio No. 169, 1909.

[2] J. S. Diller, *U.S. Geol. Surv., Bull. 38*, 1887.

[3] The writer is indebted to Professor J. E. Wolff for the description of these breccias.

[4] W. H. Weed, *U.S. Geol. Surv., Geol. Atlas*, Little Belt Mountains Folio No. 56.

magma must have been very active to bring up blocks of gneiss from such a depth.

Beemersville, New Jersey: Near Beemersville and Libertyville, New Jersey, are several masses of breccia whose form suggests narrow volcanic necks or stocks. The occurrences have been described by Kemp[1] and by Wolff.[2]

The fragments are of various sizes from bowlders to fine grains and consist of gneiss, granite, limestone, and shale (the country rock), imbedded in an ouachitite. The shale inclusions show very sharp angular edges. The presence of inclusions of gneiss show that there has been vertical transportation of nearly a mile. Here again the elliptical-shaped intrusions have probably come up by replacing the rock through which they have passed, and the inclusions probably represent the stoped blocks.

There are also a number of lamprophyric dikes in the region which contain abundant inclusions of the rocks which they cut.

SUMMARY

Inclusions in dikes are rare and are due to special or to accidental causes. The majority of the inclusions have been shattered from the walls of the dike either in the formation of the fissure through which the dike came or in the injection of the dike-magma. The shattering is largely a mechanical operation, but thermal and mechanical action may be combined in many cases. In a few instances the inclusions are pebbles derived from a conglomerate.

The direction and amount of the movement of the inclusions in the several examples are shown in the table on p. 181.

In the cases where some inclusions rise and others sink in the same dike, as at LaTrappe near Montreal, the movement does not appear to depend as much upon the specific gravity of the magma relative to that of the inclusions as upon the mechanics of intrusion and the circulation in the dike-magma before its consolidation. Sandstone fragments have descended in this dike although their specific gravity when in the magma was probably

[1] "On Certain Porphyritic Bosses in Northern New Jersey," *Amer. Jour. Sci.* (3), XXXVIII (1889), 130–34.

[2] *U.S. Geol. Surv., Geol. Atlas*, Franklin Furnace Folio No. 161, p. 13.

less than that of the magma. In the other cases where the inclusions have sunk, the fragments are composed of various rocks including quartzite, sandstone, slate, limestone, gneiss, and diabase.

Examples	Movement of Inclusions		
	None	Up	Down
Cornwall	×		
Mexico	×		
Cape Ann	×		
Montreal	×	3,000 ft.	2,000+ft.
Marblehead			1,000+ft.
Southern Sweden			×
Cripple Creek			×
Pequawket			×
Brazil		?	×
Shelburne Point	×	12,000+ft	
Mancos		×	
Aschaffenburg		×	
Somerville		×	
Rossland		×	
Ogunquit		×	
Little Belt Mountains		×	
Syracuse	×	4,000 ft.	
Beemersville	×	×	
Crazy Mountains	×	24,000 ft.	

Inclusions in dikes are in general rounded when they have come from some depth and angular when near the place of origin. This indicates that the rounding is largely due to friction which varies with: (1) the distance through which the inclusion has moved, (2) the number of the inclusions; (3) the width of the dike, (4) the temperature of the inclusion at the time of the shattering, (5) the rate of movement of the inclusion.

The initial temperature of the outside of an inclusion is the mean between that of the magma and that of the center of the inclusion. Hence, if there is a fused contact around an inclusion or if the latter shows resorption, a high temperature of the whole fragment is indicated. As most dikes are quickly chilled, it is seldom possible to heat cold inclusions to a temperature at which fusion can take place around their peripheries. In dikes several hundred feet wide, as those of southern Sweden, cold inclusions may be heated to such a high temperature that partial resorption results. In narrower dikes, partial resorption of fragments is possible only

where a special mechanism for the transfer of heat from depth exists for a relatively long period of time, as in a part of the Ogunquit dike.

The material worn from fragments during their rounding and the cement which is dissolved from conglomerates appear in the dike as xenocrysts. Thus, in the hand-specimen of the Rossland dike many small fragments of quartzite and gneiss one-quarter of an inch or less in length may be seen. In the Brevik (Sweden) dike Hedström reports grains of quartz and feldspar of microscopic size derived from the matrix of the conglomerate. In the Somerville dikes numerous xenocrysts of quartz and andesine feldspar, which have come in part from the inclusions, are found in the groundmass. The Shelburne Point dike described by Hitchcock contains many small fragments of the inclusion-rocks.

The question of the fragmentation of rocks from the differential expansion of the constituent minerals and the importance of the inversion point of quartz are of bearing in quartzose inclusions only in the cases where the inclusions have been heated to about 575° C. The criteria of high temperature of the inclusions, at the time of the chilling of the dike, are fused contacts or evidences of corrosion. In part of the Ogunquit dike there is evidence of high temperature and partial assimilation of the inclusions, most of which contain only a small amount of quartz. This corrosion apparently proceeds by the fragmentation of the minerals, as xenocrysts are exceedingly abundant in the dike-rock. In the Somerville dikes the inclusions of feldspar and vein quartz show marked corrosion, yet there is no sign of fragmentation at their peripheries. In the Aschaffenburg dikes there has been a selective formation of xenocrysts of certain minerals as if the rocks had been disrupted by the unequal expansion of the different minerals.

In conclusion it may be stated that some knowledge concerning the mechanism of dike-injection may be gained by the consideration of the movements of the inclusions. Further observations are needed concerning the possibility of circulation which will cause inclusions of lesser specific gravity than the dike-magma to descend in dikes.

SUMMARIES OF PRE-CAMBRIAN LITERATURE OF NORTH AMERICA FOR 1909, 1910, 1911, AND PART OF 1912

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II. EASTERN PART OF NORTH AMERICA

Miss Bascom[1] states that the oldest rocks of the Philadelphia district are the Baltimore gneiss and the Wissahickon mica gneiss. Their relation to each other is uncertain. Both are intruded by granites and gabbros.

The Baltimore gneiss presents a granitic and a gneissic phase. The latter consists of alternating, fine-grained layers of mica, quartz, and feldspar. The granitic variety contains quartz, feldspar, and accessories of biotite, hornblende, and garnets. The alternation of layers in the gneiss is regarded by Miss Bascom as evidence of sedimentary origin.

Miss Bascom believes that the Baltimore gneiss is approximately of the same age as the Fordham gneiss of New York, the Stamford gneiss of New England, and the Carolina gneiss of Virginia.

The pre-Cambrian rocks of the Trenton, N.J., district as described by Miss Bascom[2] consist of Baltimore gneiss and the Wissahickon mica gneiss, both of which she regards as of sedimentary origin. Besides these, there are granitic and gabbroic instrusives.

Bastin[3] states that the Adirondack graphite deposits occur in schists of sedimentary origin. Two types of occurrence are recognized, one related to the dynamic metamorphism of carbonaceous

[1] *Philadelphia Folio*, U.S. Geological Survey Folio 162, 23 pp., 12 pls., sections, maps, illustrations, 1909.

[2] F. Bascom *et al.*, *Trenton Folio*, U.S.G.S. Folio 167, 24 pp., 4 pls., 3 figs., 1909.

[3] Edson S. Bastin, "Origin of Certain Adirondack Graphite Deposits," *Econ. Geol.*, V, No. 2 (1910), 134–57.

sediments of the sand clay type, the other to both dynamic and contact metamorphism.

Bayley[1] states that the pre-Cambrian of New Jersey consists essentially of three series of gneisses, sodic, potassic, and basic, respectively, accompanied by pegmatites, all intrusive into still older limestones, the Franklin limestone. The gneisses contain magnetite ores in form pod shaped, northeastward-pitching shoots having the same structural attitude as the gneisses, and are frequently offset by cross and longitudinal faults. The ores are titaniferous, and are associated with basic and alkaline silicates. The Franklin limestone also contains some magnetite ores. These are non-titaniferous, veinlike masses, associated with heavy lime silicates and calcite.

Cushing[2] *et al.* state that the pre-Cambrian succession of the Thousand Islands' region may be classified, beginning with the oldest, as: (1) Grenville metamorphosed sediments, consisting of marbles, schists, gneisses, quartzites which originally were sandstones, shales, and limestones; (2) granite gneisses intrusive into the Grenville, and which have changed the Grenville into amphibolites along the contacts; (3) small bodies of massive syenite, gabbro, and granite; (4) unmetamorphosed basic dikes.

This region shows less complexity of folding, a greater dominance of acid intrusives, and fewer basic igneous rocks than the northern Adirondacks. It is regarded as a transition between the Adirondacks and the Grenville area of Canada.

Dale and Gregory[3] state that the Becket granite gneiss of probably pre-Cambrian age outcrops over wide areas in northern Litchfield county, Connecticut.

Emmons and Laney[4] state that the pre-Cambrian in the Ducktown district consists of the Carolina gneiss, a series of gneisses

[1] W. S. Bayley, "Iron Mines and Mining in New Jersey," *Geol. Survey of New Jersey*, Vol. VII, 499 pp., 23 pls., 2 maps, 31 figs.

[2] H. P. Cushing, H. L. Fairchild, R. Ruedmann, and C. H. Smith, Jr., "Geology of the Thousand Islands' Region," *New York State Mus. Bull.* 145, 194 pp., 63 pls., 6 maps, 9 figs., 1910.

[3] T. Nelson Dale and Herbert E. Gregory, "The Granites of Connecticut," *Bull. 484, U.S. Geological Survey*, 1911. Several maps.

[4] W. H. Emmons and F. B. Laney, "Preliminary Report on the Mineral Deposits of Ducktown, Tennessee," *Bull. 470, U.S. Geological Survey*, 1910.

which probably were developed from the metamorphism of granites, and other igneous rocks and possibly some sediments. It is associated with and probably intruded by the Roan gneiss, which seems to have been diorite and gabbro mainly. Both the Carolina and Roan gneiss are intruded by a younger, less altered granite.

Gordon[1] states that one of the major stratigraphic problems of eastern North America is the separation of the pre-Cambrian from the early Paleozoic sediments and the subdivision of the pre-Cambrian. The problem is complicated by structural intricacy and metamorphism.

Gordon[2] reports that granitic hornblende and mica gneisses, quartzite, and basic eruptives of pre-Cambrian age are found within the Poughkeepsie quadrangle.

Kemp and Ruedemann[3] state that the pre-Cambrian rocks of the Elizabethtown and Port Henry quadrangles of the northwestern part of the Adirondack region may be classified in order of age from latest to the oldest as follows: (1) the unmetamorphosed basaltic dikes; (2) the eruptive complex of more or less metamorphosed granite, anorthosite, syenite, gabbros, and intermediate types; (3) the Grenville series of limestones, ophicalcites, schists, and sedimentary gneisses. The syenites contain lens or podlike bodies of nontitaniferous magnetite with apatite. The hanging wall is generally more acid than the footwall. Locally the gabbros consist dominantly of magnetite and ilmenite.

Kemp[4] summarizes the characteristics of the pre-Cambrian of New York and points out some of its striking similarities to the pre-Cambrian of Sweden.

The oldest pre-Cambrian rocks of the Adirondack are the Grenville sedimentary gneisses and schists, intruded by batholiths of granite gneisses. These were intensely folded and then intruded in the order of time by anorthosite, syenite, basic gabbros, and

[1] C. E. Gordon, "Some Geologic Problems," *Science*, N.S., XXIX (1909), 901–3.

[2] C. E. Gordon, "Progress Report on Poughkeepsie Quadrangle," *New York State Museum Bull. 140*, 1910, pp. 16–20.

[3] "Geology of the Elizabethtown and Port Henry Quadrangles," *New York State Museum Bull. 138*, 1910, 173 pp., 21 pls., 36 figs.

[4] J. F. Kemp, "Pre-Cambrian Formations in the State of New York," Congrès Géologie International, 1910, pp. 699–717.

basalt and porphyry dikes. At Mineville, the syenites are associated with magnetite ores, which in their phosphorus content and in the composition of their wall rocks resemble those of Kiruna. The intrusive episode was followed by intense folding and long-continued erosion. The Paleozoic rocks like those of Sweden were here deposited upon an undulating floor of moderate relief. In New York, evidences of old pre-Cambrian valleys filled by Paleozoics have been found. The visible contacts between the pre-Cambrian and the Paleozoic rocks in the Adirondacks as in Sweden are partly depositional and partly along faults.

The oldest pre-Cambrian rocks in the southeastern area of New York are the Fordham gneiss, consisting dominantly of sedimentary rocks intruded by granite batholiths. Kemp correlates the Fordham gneiss with the Grenville series on the basis of lithologic similarity, and identity of stratigraphic position. Above the Fordham gneiss lie the Manhattan schists and Inwood marble, both metamorphosed sedimentary formations, but less metamorphosed than the Fordham gneiss. They are intruded by plutonic rocks showing a wide range of composition which show parallelism to the Subjotnian of Sweden in their stratigraphic relations, but not in their petrographic characteristics. The Manhattan schists and Inwood limestones Kemp believes may be parallel to the Huronian of the Lake Superior region and the Jatulian of Sweden and Finland.

Kümmel[1] states that the pre-Cambrian rocks comprise a series of basic gneisses and limestones, which are cut by acid gneisses, and pegmatites, all of which lie unconformably beneath the Cambrian. The gneisses are nearly all mineralogically and chemically equivalent to basic and acid igneous rock types, and are largely, if not entirely of igneous origin. The acid intrusives present no evidence of crushing, which probably means that their foliation was developed during crystallization by deformative stresses. The limestones are associated with magnetite ores, and with the Franklin Furnace and Sterling Hill zinc ores. The present state of crystallization, and structural character of the rocks, as well as the develop-

[1] Henry B. Kümmel, "Geological Section of New Jersey," *Jour. Geol.*, XVII, No. 4 (1909), 351–80.

ment of ores, probably resulted from one brief period of deformation and intrusion.

Koeberlein[1] describes the Brewster district as a part of the pre-Cambrian area of New York City, about 54 miles to the northwest of the city. The abandoned Tilly Foster, Brewster, and Croton mines are located here. The stratigraphy from the bottom is reported as Fordham gneiss comprising three series, sedimentary, granitic, and syenitic, respectively, followed by the Inwood limestone and the Manhattan schists intruded by diorites and pegmatite.

The ores are titaniferous and non-titaniferous magnetites, closely related to the syenite of the Fordham gneiss. The syenite contains magnetite, apparently the last mineral to crystallize. The titaniferous magnetites are regarded as magmatic segregations. The non-titaniferous ore of the Tilly Foster mine is regarded as a replacement of limestone by solutions given off during the cooling of the syenite. The gangue consists of chondrodite, garnets, and other minerals characteristic of the deep-seated metamorphism of limestones.

W. J. Miller[2] states that the oldest rocks of the Remsen and Port Leyden Quadrangles of the southwestern part of the Adirondack Mountains are the Grenville sediments, originally sandstones, shales, and limestones which were altered to gneisses and crystalline limestones by syenite intrusions and complex folding, before Cambrian time.

Stose[3] states that the pre-Cambrian rocks of the Mercersburg-Chambersburg area of Pennsylvania consist of a series of altered basalt flows overlaid by altered, finely laminated, spherulitic, and porphyritic rhyolite lava.

Watson[4] reports that an insignificant tonnage of manganese ore has been mined in the crystalline schists of Georgia, which are at

[1] F. R. Koeberlein, "Brewster Iron-bearing District of New York," *Econ. Geol.*, IV (1909), 714–54.

[2] W. J. Miller, "Geology of the Remsen Quadrangle," *New York State Museum Bull. 126*, 1909, 51 pp., 11 pls., 4 figs., 1 geol. map; "Geology of the Port Leyden Quadrangle," *New York State Museum Bull. 135*, 1910, 61 pp., 5 figs.

[3] G. W. Stose, *Mercersburg-Chambersburg Folio*, U.S.G.S. Folio 170, 19 pp., 8 pls., 5 figs., 1909.

[4] Thomas L. Watson, "The Manganese Ore Deposits of Georgia," *Econ. Geol.*, IV (1909), 46-55.

least partly of pre-Cambrian age. Most of the ores occur in a residual clay derived from the decay of crystalline schists. The minerals composing the ores are generally oxides, but silicates are also represented, the latter being somewhat abundant in the undecayed rocks.

Woodman[1] states that the pre-Cambrian mountain protaxis of Cape Breton, Nova Scotia, is not well known. Certain iron-bearing dolomites called the George River limestone may be Upper pre-Cambrian.

[1] J. E. Woodman, "Report on the Iron Ore Deposits of Nova Scotia," *Canada Dept. of Mines*, 1909.

[*To be continued*]

Reviews

Atlas photographique des formes du relief terrestre. Prepared by an International Commission *a quarto*. Genève (Suisse): Fred. Boissonas et Cie.

Part I of the first series of plates in this atlas has been issued and distributed. In this part there are eight excellent plates chosen to illustrate the land forms produced by rock disintegration and the action of gravity. These plates were selected from a vast number of subjects submitted by members of the International Commission appointed by the ninth International Congress of Geographers. This commission was directed to co-operate in the preparation of the most comprehensive atlas of relief forms of the earth that has ever been prepared for publication.

The burden of the work has fallen upon the three members of the executive committee, Professors Jean Brunhes, Emm. de Martonne, and Emile Chaix, and to these men much appreciation and praise is due for the excellency and attractiveness of this first number.

The plates included in this first part are the following:

Plate 1.—Disintegration controlled by structure (photographs by M. Lugeon). Disintegration partly independent of. structure (photographs by Jean Brunhes, E. de Cholnoky).

Plate 2.—Exfoliation of granite (photographs by G. K. Gilbert, H. W. Turner).

Plate 3.—Exfoliation of granite (photographs by H. W. Turner, C. D. Walcott).

Plate 4.—Peaks formed by frost weathering (photographs by L. Duparc).

Plate 5.—Rock pinnacles (photographs by L. Duparc, E. Chaix).

Plate 6.—Forms due to weathering in the "Dolomites" (photographs by O. Lehmann).

Plate 7.—Crumbling ridge in high mountain and in the polar regions (photographs by E. Chaix, E. de Cholnoky).

Plate 8.—Mechanical disintegration and chemical decomposition combined (photographs by E. Chaix).

Each plate is a phototype printed on special paper 10×13.3 inches. It is accompanied by a description published in three languages, one of which, in each case, is English. These plates and their descriptions

are issued on separate sheets, so that they may easily be made of immediate and permanent educational value in the laboratories of geography and geology, and each such laboratory in America should make arrangements for at least one complete copy of the atlas before the edition is exhausted.

The general plan of the atlas includes:

1. Forms produced by disintegration and the action of gravity: mechanical and chemical disintegration; rock-waste, landslides, etc.

2. Elementary forms produced by erosion by running water: ravining, erosion in swirls, torrents, etc.

3. Complex forms produced by erosion by running water: gorges, valleys; maturity more or less advanced; successive cycles.

4. Forms affected by the character of the rocks: massive, slaty, incoherent, permeable, and soluble rocks.

5. Forms produced by erosion of rocks of various structures: surface features associated with folding and faulting; epirogenic movements.

6. Forms connected with glacial action: existing glaciers, erosion and deposit; ice age.

7. Forms of desert regions: wind erosion; dunes, etc.; complex desert forms.

8. Coastal forms: simple forms due to erosion and accumulation; changes of shore line.

9. Volcanic land forms: accumulation (cones, lava flows, etc.), forms produced by denudation.

The completed atlas will contain 10 series of 6 parts each. Each series will contain from 45–48 plates, so that the atlas will include 450–80 plates and from 1800 to 1900 pages of descriptions, illustrated with maps and diagrams.

W. W. A.

The Fuels Used in Texas. By WILLIAM B. PHILLIPS and S. H. WORRELL. Bull. of the University of Texas, No. 307. 1913. Pp. 287, pls. 22.

The fuels used in Texas are natural gas, oil, sub-bituminous coal, and lignite. All these fuels are produced in the state. For the year 1912 the production of oil was 12,000,000 barrels, 1,200,000 tons of sub-bituminous coal, and 990,000 tons of lignite.

The sub-bituminous coal is mined in three fields. In the north-central part of the state Carboniferous beds carry coal, and on the Rio Grande in two localities coal is worked in beds that are probably Cretaceous. The coal seams are not more than two feet thick in any place.

The object of the report is to emphasize the fact that lignite properly utilized is a valuable commercial fuel. Lignite is well distributed over the state, but it is especially valuable in the northeastern part. It is included in the Timber Belt, Yegua, and Fayette formations of the Eocene period, in the first of which it is most abundant, and there the individual seams reach a thickness of 15 feet.

The value of lignite is shown by chemical analyses and by results of boiler tests. Exclusive of expense of handling, the cost of evaporating 1,000 pounds of water is, on the average, with coal as fuel, 30 cents per pound of water, with lignite, 20 cents, and with oil, 15 cents. Natural gas is the cheapest fuel, but it is obtainable only locally. Lignite may be used as raw coal, as fuel under stationary boilers, as a fuel in gas-producers, for briquetting raw or dried, and for dry distillation and recovery of by-products. It is actually used mostly as raw fuel under stationary boilers. The authors strongly support the report of Dean Babcock of the University of North Dakota that the chief value of lignite will be obtained from its briquetting. They agree that it is almost hopeless to attempt to make useful briquettes out of raw lignite, but that by carbonization (driving-off of the volatile gases), or partial carbonization of the coal and briquetting of the carbon-high product, a commercial fuel may be made which will be of the same order of efficiency as anthracite.

T. T. Q.

Geology of the Titanium and Apatite Deposits of Virginia. By THOMAS LEONARD WATSON and STEPHEN TABER. Virginia Geol. Sur. Bull. No. III–A. 1913. Pp. 300, pls. 37, figs. 22, map 1.

The titanium and apatite deposits of Virginia are in the northwestern part of the state. Rutile is found both in massive syenite and in nelsonite dikes. The apatite is most abundant in some of the nelsonite dikes. The report discusses the subject of titanium quite fully. The chemistry of titanium, its ores, their distribution, and the uses of titanium products are treated fully. Titanium is used in metallic alloys, such as ferro-titanium, cupro-titanium, etc., for lighting purposes as incandescent media, as mordants, as refractory coloring materials for the ceramic industry, etc.

The rocks in the area are igneous in origin and distinctly metamorphosed. They form a peculiar comagmatic group which is characterized by the abundance of ilmenite, rutile, and apatite. These minerals

are the economic values. Other peculiar mineral constituents are blue, opalescent quartz, hypersthene, and hornblende derived from pyroxene. Named in order of their probable differentiation, the principal rock types of the area are: biotite-quartz, monzonite-gneiss, syenite formerly referred to as pegmatite, gabbro, nelsonite, and diabase.

The geology of the ore deposits is fully discussed with especial description of the unusual rock types. The ore minerals occur most abundantly in the nelsonite. The chief constituents of this rock are apatite and ilmenite; there are varieties of nelsonite which are rich in rutile. The nelsonite bodies are of remarkably uniform granularity, irrespective of the size or of the width of the body. Some show evidence of mineralogical gradation into the composition of the wall rock, whereas others show sharp differentiation of the nelsonite and the inclosing rock. It is supposed that the nelsonite dikes were intruded into the still very hot, and possibly in some places unsolidified, rock. The rutile-rich bodies appear to have been formed in advance of the ilmenite nelsonites; this is suggested by their irregularity in boundary, and by their appearance of transition into the surrounding rock like segregations rather than intrusions. Both types are regarded as differentiation facies of the inclosing rocks.

This district contains the richest and greatest known deposit of titanium minerals in the world. With an increase in the utilization of titanium products it is expected that this will become a productive mining region. The apatite deposits will not be of much importance commercially while Florida remains as productive of phosphates as at present. The Virginia deposits both of titanium and of apatite have been worked intermittently but the present output is insignificant.

T. T. Q.

The Ore Deposits of Northeastern Washington. By HOWLAND BANCROFT. U.S. Geol. Surv. Bull. No. 550. Pp. 215, figs. 26, pls. 19.

Except for a brief discussion of the general geologic features of northeastern Washington by way of introduction, this bulletin is given over for the most part to descriptions of mines and prospects in the various districts included. In the discussion of each district some attention is given to the origin of the ores, but the discussion is broadly general. A section on the Republic District, written by Lindgren, is included in the volume.

A. D. B.